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ABSTRACT

The purpose of this water treatment field study training program is to: (1) develop new qualified water treatment plant operators; (2) expand the abilities of existing operators, permitting better service both to employers and public; and (3) prepare operators for civil service and certification examinations (examinations administered by state/professional associations which operators take to indicate a level of professional competence). This 10-chapter volume contains information on: what water treatment plant operators do; how to manage reservoirs and intake structures; how to operate and maintain coagulation, flocculation, sedimentation, and filtration water treatment processes; disinfection of water; procedures for controlling corrosion; techniques for identifying the causes of taste and odor problems and suggestions for correcting such problems; procedures for operating, maintaining, and administrating a water treatment plant; and basic laboratory procedures. Objectives, glossary, lessons, questions (with suggested answers), and test are provided for each chapter. Final examination (with answers), solving water treatment plant arithmetic problems, water abbreviations, complete glossary, and subject index are provided in an appendix. Program scope/sequence and instructions to participants in home-study courses are provided in the introduction. (JN)

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WATER TREATMENT PLANT OPERATION

Volume I

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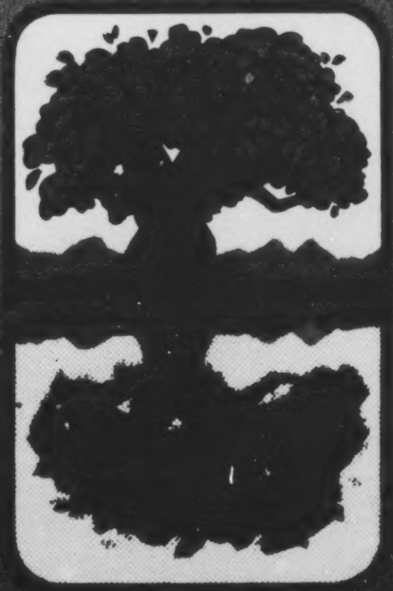

A Field Study

SE041444

Environmental Protection Agency Review Notice

This training manual has been reviewed by the Office of Drinking Water, U.S. Environmental Protection Agency and the California Department of Health Services. Both agencies have approved this manual for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Environmental Protection Agency nor the California Department of Health Services. Mention of trade names or commercial products does not constitute endorsement or recommendations for use by the Environmental Protection Agency; California Department of Health Services; California State University, Sacramento; National Environmental Training Association; authors of the chapters or project reviewers, consultants, and directors.

WATER TREATMENT PLANT OPERATION

Volume I

A Field Study Training Program

prepared by

California State University, Sacramento
School of Engineering
Applied Research and Design Center

in cooperation with the

National Environmental Training Association

****

Kenneth D. Kerri, Project Director

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for the

California Department of Health Services
Sanitary Engineering Branch
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and

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Office of Drinking Water
Grant No. T-901361-01-0

1983

OPERATOR TRAINING MANUALS IN THIS SERIES are available from Ken Kerri, California State University, Sacramento, 6000 J Street, Sacramento, CA 95819, phone (916) 454-6142.

1. *WATER SUPPLY SYSTEM OPERATION*, 1 Volume,
2. *WATER TREATMENT PLANT OPERATION*, 2 Volumes,
3. *OPERATION OF WASTEWATER TREATMENT PLANTS*, 3 Volumes, and
4. *OPERATION AND MAINTENANCE OF WASTEWATER COLLECTION SYSTEMS*, 1 Volume.

NOTICE

This manual is revised and updated before each printing based on comments from persons using this manual.

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PREFACE

The purposes of this water treatment field study training program are to:

1. Develop new qualified water treatment plant operators,
2. Expand the abilities of existing operators, permitting better service to both their employers and the public, and
3. Prepare operators for civil service and *CERTIFICATION EXAMINATIONS*.[1]

CERTIFICATION
EXAMINATION

To provide you with the knowledge and skills needed to operate and maintain water treatment plants as efficiently and effectively as possible, experienced water treatment plant operators prepared the material in each chapter of this manual.

Water treatment plants vary from city to city and from region to region. The material contained in this program is presented to provide you with an understanding of the basic operation and maintenance aspects of your water treatment plant and with information to help you analyze and solve operation and maintenance problems. This information will help you operate and maintain your plant in a safe and efficient manner.

Water treatment plant operation and maintenance is a rapidly advancing field. To keep pace with scientific and technological advances, the material in this manual must be periodically revised and updated. *THIS MEANS THAT YOU, THE OPERATOR, MUST RECOGNIZE THE NEED TO BE AWARE OF NEW ADVANCES AND THE NEED FOR CONTINUOUS TRAINING BEYOND THIS PROGRAM.*

The Project Director is indebted to the many operators and other persons who contributed to this manual. Every effort was made to acknowledge material from the many excellent references in the water treatment field. Reviewers Leonard Ainsworth, Jack Rossum, and Joe Monscvitz deserve special recognition for their extremely thorough review and helpful suggestions. John Trax, Chet Pauls, and Ken Hay, Office of Drinking Water, U.S. Environmental Protection Agency, and John Gaston, Bill MacPherson, Bert Ellsworth, Clarence Young, Ted Bakker, and Beverlie Vandre, Sanitary Engineering Branch, California Department of Health Services, all performed outstanding jobs as resource persons, consultants and advisors. Larry Hannah served as Education Consultant. Illustrations were drawn by Martin Garrity. Charlene Arora helped type the field test and final manuscript for printing. Special thanks are well deserved by the Program Administrator, Gay Kornweibel, who typed, administered the field test, managed the office, administered the budget, and did everything else that had to be done to complete this project successfully.

KENNETH D. KERRI
PROJECT DIRECTOR

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[1] *Certification examination. An examination administered by a state or professional association that operators take to indicate a level of professional competence. In most states the Chief Operator of a plant must be "certified" (successfully pass a certification examination). Certification is voluntary in a few states. Current trends indicate that certification of operators will be mandatory in all states in the near future.*

OBJECTIVES OF THIS MANUAL

Proper installation, inspection, operation, maintenance, repair and management of water treatment plants have a significant impact on the operation and maintenance costs and effectiveness of the plants. The objective of this manual is to provide water treatment plant operators with the knowledge and skills required to operate and maintain water treatment plants effectively, thus eliminating or reducing the following problems.

1. Health hazards created by the production or output of unsafe water from the plant;
2. System failures that result from the lack of proper installation, inspection, preventive maintenance, surveillance and repair programs designed to protect the public's investment in the plant;
3. Taste and odor complaints from consumers;
4. Turbid or colored waters which are unacceptable to consumers;
5. Corrosion damages to pipes, equipment, tanks and structures at the water treatment plant and in the distribution system;
6. Complaints from the public or local officials due to the unreliability or failure of the water treatment plant to perform as designed; and
7. Fire damage caused by insufficient water at a time of need.

QUALITY
AWARD

SCOPE OF THIS MANUAL

This manual on water treatment plant operation is divided into two volumes. Volume I stresses the knowledge and skills needed by an operator working in a conventional water treatment plant used for treating surface waters. Volume II emphasizes material needed by operators trying to control iron and manganese, softening hard waters, and trihalomethanes. Also contained in Volume II is information needed by all operators responsible for the administration and management of a water treatment plant, such as maintenance, instrumentation, safety, and laboratory procedures.

Volume I contains information on:

1. What water treatment plant operators do;
2. How to manage reservoirs and intake structures;
3. How to operate and maintain coagulation, flocculation, sedimentation and filtration water treatment processes;
4. Disinfection of water;
5. Procedures for controlling corrosion;
6. Techniques for identifying the causes of taste and odor problems and suggestions for correcting such problems;
7. Procedures for operating, maintaining, and administering a water treatment plant; and
8. Basic laboratory procedures.

Volume II contains information on:

1. How to control iron and manganese;
2. Procedures for fluoridating water;
3. Techniques for softening water;
4. How to control trihalomethanes;
5. Techniques for treating dissolved solids in water;
6. Handling and disposal of process wastes;
7. Procedures for maintaining processes, equipment, and facilities;

8. How to maintain and troubleshoot instrumentation;
9. Techniques for recognizing hazards and developing safe procedures and safety programs;
10. Advanced laboratory procedures for analyzing samples of water; and
11. Water quality regulations and administrative considerations for supervisors and managers.

Material in this manual furnishes you with information concerning situations encountered by most water treatment plant operators in most areas. These materials provide you with an understanding of the basic operational and maintenance concepts for water treatment plants and with an ability to analyze and solve problems when they occur. Operation and maintenance programs for water treatment plants will vary with the age of the plant, the extent and effectiveness of previous programs, and local conditions. You will have to adapt the information and procedures in this manual to your particular situation.

Technology is advancing very rapidly in the field of operation and maintenance of water treatment plants. To keep pace with scientific advances, the material in this program must be periodically revised and updated. This means that you, the water treatment plant operator, must be aware of new advances and recognize the need for continuous personal training reaching beyond this program. *TRAINING OPPORTUNITIES EXIST IN YOUR DAILY WORK EXPERIENCE, FROM YOUR ASSOCIATES, AND FROM ATTENDING MEETINGS, WORKSHOPS, CONFERENCES AND CLASSES.*

USES OF THIS MANUAL

This manual was developed to serve the needs of operators in several different situations. The format used was developed to serve as a home-study or self-paced instruction course for operators in remote areas or persons unable to attend formal classes either due to shift work, personal reasons or the unavailability of suitable classes. This home-study training program uses the concepts of self-paced instruction where you are your own instructor and work at your own speed. In order to certify that a person has successfully completed this program, an objective test is included at the end of each chapter.

Also, this manual can serve effectively as a textbook in the classroom. Many colleges and universities have used similar manuals as texts in formal classes (often taught by operators). In areas where colleges are not available or are unable to offer classes in the operation of water treatment plants, operators and utility agencies can join together to offer their own courses using the manual.

Cities or utility agencies can use the manual in several types of on-the-job training programs. In one type of program, a manual is purchased for each operator. A senior operator or a group of operators are designated as instructors. These operators help answer questions when the persons in the training program have questions or need assistance. The instructors grade the objective tests at the end of each chapter, record scores and notify California State University, Sacramento, of the scores when a person successfully completes this program. This approach eliminates any waiting while papers are being graded and returned by CSUS.

This manual was prepared to help operators operate and maintain their water treatment plants. Please feel free to use the manual in the manner which best fits your training needs and the needs of other operators. We will be happy to work with you to assist you in developing your training program. Please feel free to contact

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INSTRUCTIONS TO PARTICIPANTS IN HOME-STUDY COURSE

Procedures for reading the lessons and answering the questions are contained in this section.

To progress steadily through this program, you should establish a regular study schedule. For example, many operators in the past have set aside two hours during two evenings a week for study.

The study material is contained in two volumes divided into 23 chapters. Some chapters are longer and more difficult than others. For this reason, many of the chapters are divided into two or more lessons. The time required to complete a lesson will depend on your background and experience. Some people might require an hour to complete a lesson and some might require three hours; but that is perfectly all right. *THE IMPORTANT THING IS THAT YOU UNDERSTAND THE MATERIAL IN THE LESSON!*

Each lesson is arranged for you to read a short section, write the answers to the questions at the end of the section, check your answers against suggested answers; and then *YOU* decide if you understand the material sufficiently to continue or whether you should read the section again. You will find that this procedure is slower than reading a normal textbook, but you will remember much more when you have finished the lesson.

At the end of each chapter, you will find an "objective test." Mark your answers on the special answer sheet provided for each chapter. Some discussion and review questions are provided following each lesson in the later chapters. These questions review the important points you have covered in the lesson.

The objective test at the end of each lesson contains true or false, multiple-choice, fill-in-the-blank, or match-the-answers types of questions. The purposes of this exam are to review the chapter and to give experience in taking different types of exams. *MAIL TO THE PROGRAM DIRECTOR ONLY YOUR ANSWERS TO OBJECTIVE TESTS ON THE PROVIDED ANSWER SHEETS.*

After you have completed the last objective test, you will find a final examination. This exam is provided for you to review how well you remember the material. You may wish to review the entire manual before you take the final exam. Some of the questions are essay-type questions which are used by some states for higher-level certification examinations. After you have completed the final examination, grade your own paper and determine the areas in which you might need additional review before your next certification or civil service examination.

You are your own teacher in this program. You could merely look up the suggested answers from the answer sheet or copy them from someone else, but you would not understand the material. Consequently, you would not be able to apply the material to the operation of your plant nor recall it during an examination for certification or a civil service position.

YOU WILL GET OUT OF THIS PROGRAM WHAT YOU PUT INTO IT.

SUMMARY OF PROCEDURE

A. OPERATOR (YOU)

1. Read what you are expected to learn in each chapter (the chapter objectives).
2. Read sections in the lesson.
3. Write your answers to questions at the end of each section in your notebook. You should write the answers to the questions just as you would if these were questions on a test.
4. Check your answers with the suggested answers.
5. Decide whether to reread the section or to continue with the next section.
6. Write your answers to the discussion and review questions at the end of each lesson in your notebook.
7. Mark your answers to the objective test on the answer sheet provided by the Project Director or by your instructor.

8. Mail material to Project Director. (Send *ONLY* your completed answer sheet.)

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PROJECT DIRECTOR

B. PROJECT DIRECTOR

1. Mails answer sheet for each chapter to operator.
2. Corrects tests, answers any questions, and returns results to operators.

C. ORDER OF WORKING LESSONS

To complete this program you will have to work all of the lessons. You may proceed in numerical order, or you may wish to work some lessons sooner.

SAFETY IS A VERY IMPORTANT TOPIC. Everyone working in a water treatment plant must always be safety conscious. Operators daily encounter situations and equipment that can cause a serious disabling injury or illness if the operator is not aware of the potential danger and does not exercise adequate precautions. For these reasons you may decide to work on the chapter on "Safety" early in your studies. In each chapter, SAFE PROCEDURES ARE ALWAYS STRESSED. See Chapter 20, "Safety," Volume II, for details.

SAFE PROCEDURES ARE ALWAYS STRESSED

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by George Uyeno

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by Joe Monscvitz

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by Jim Sequeira

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CHAPTER 1

THE WATER TREATMENT PLANT OPERATOR

by

Ken Kerri

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OBJECTIVES

Chapter 1. THE WATER TREATMENT PLANT OPERATOR

At the beginning of each chapter in this manual you will find a list of *OBJECTIVES*. The purpose of this list is to stress those topics in the chapter that are most important. Contained in the list will be items you need to know and skills you must develop to operate, maintain, repair and manage a water treatment plant as efficiently and as safely as possible.

Following completion of Chapter 1, you should be able to:

1. Explain the type of work done by water treatment plant operators,
2. Describe where to look for jobs in this profession, and
3. Describe how you can learn to do the jobs performed by water treatment plant operators.

CHAPTER 1. THE WATER TREATMENT PLANT OPERATOR

Chapter 1 is prepared especially for new operators or people interested in becoming water treatment plant operators. If you are an experienced water treatment plant operator, you may find some new viewpoints in this chapter.

1.0 NEED FOR WATER TREATMENT PLANT OPERATORS

People need safe water to drink. Many sources of water are not directly suitable for drinking purposes without treatment because of pollution and contamination by man and nature. Before modern society and the intensive use of available water resources, sun, wind, filtration through soil, and time purified water. Today water treatment plants are built to provide us with safe drinking water. Thus, nature is given an assist by a team consisting of designers, builders, and treatment plant operators. Designers and builders occupy the scene for only a short time, but operators go on forever. Water treatment plant personnel operate, maintain, repair and manage water treatment plants. These operators have the responsibility of producing safe and pleasant drinking water from their plants. Cities and towns need qualified, capable, and dedicated operators to do these jobs.

The need for *RESPONSIBLE* water treatment plant operators cannot be over stressed. You, as a water treatment plant operator, have the responsibility for the health and well being of the community you serve. Yes, you are responsible for the drinking water of your community and anytime you fail to do your job, you could be responsible for an outbreak of a water-borne disease which could even result in death. As an operator, you do not want the knowledge that you were negligent in your duty and, as a result, were responsible for the death of a fellow human being.

QUESTIONS

Below are some questions for you to answer. You should have a notebook in which you can write the answers to the questions. By writing down the answers to the questions, you are helping yourself learn and retain the information. After you have answered all the questions, compare your answers with those given in the Suggested Answer section on page 11. Reread any sections you do not understand and then proceed to the next section. You are your own teacher in this training program, and *YOU* should decide when you understand the material and are ready to continue with new material.

1.0A Why is there a need for water treatment plant operators?

1.0B Why do many sources of water need treatment?

1.0C Why must water treatment plant operators be responsible persons?

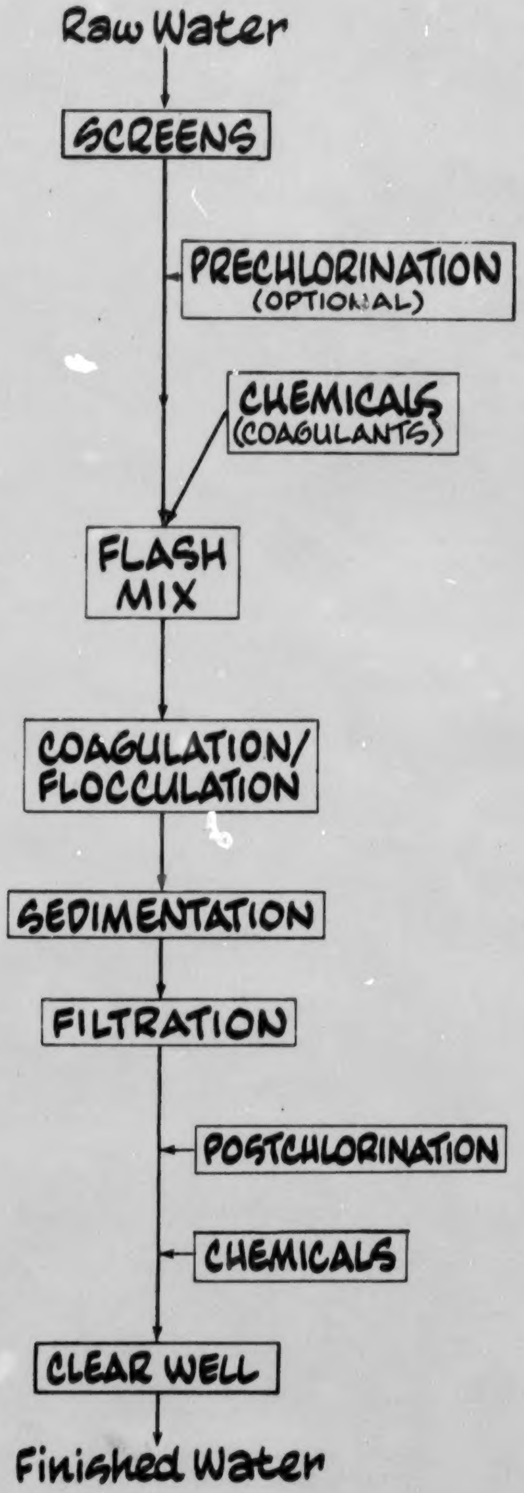
1.1 WHAT IS A WATER TREATMENT PLANT?

1.10 Conventional Surface Water Treatment Plant

The purpose of a water treatment plant is to produce safe and pleasant drinking water. This water must be free of disease-causing organisms and toxic substances. Also, the water should not have a disagreeable taste, odor or appearance.

A water treatment plant takes raw water from a source such as a stream or lake and passes the water through a series of treatment processes. The raw water flows through tanks or basins where chemicals are added and mixed with it. Then the water slowly flows through larger tanks which allow the heavier suspended solids to settle out. Any remaining solids are removed by filtration and the water is disinfected. The size of a water treatment plant as well as the number and specific types of processes it uses will depend on several factors: (1) the impurities in the raw water, (2) water quality (purity) standards, (3) the demand for water by the population being served, (4) fire protection, and (5) cost considerations.

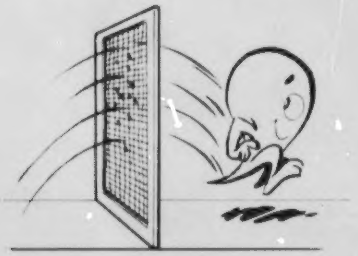
To describe a water treatment plant, we will follow a drop of water as it passes through a typical or conventional surface water treatment plant. Most surface waters receive this type of treatment. Figure 1.1 shows a flow diagram of water treatment plant processes and the purpose or function of each process. Figure 1.2 illustrates the flow pattern through a water treatment plant. In this figure both the plan (top view) and the profile (side view) are provided to help you visualize the appearance of a water treatment plant.


Raw Water
SCREENS
PRECHLORINATION (OPTIONAL)
CHEMICALS (COAGULANTS)
FLASH MIX
COAGULATION/ FLOCCULATION
SEDIMENTATION
FILTRATION
POSTCHLORINATION
CHEMICALS
CLEAR WELL
Finished Water

TREATMENT PROCESS	PURPOSE
Raw Water	
SCREENS	Removes leaves, sticks, fish & other large debris.
PRECHLORINATION (OPTIONAL)	Kills most disease causing organisms & helps control taste and odor causing substances.
CHEMICALS (COAGULANTS)	Causes very fine particles to clump together into larger particles.
FLASH MIX	Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water.
COAGULATION/ FLOCCULATION	Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration processes.
SEDIMENTATION	Settles out larger suspended particles.
FILTRATION	Filters out remaining suspended particles.
POSTCHLORINATION	Kills disease-causing organisms. Provides chlorine residual for distribution system.
CHEMICALS	Controls corrosion.
CLEAR WELL	Provides chlorine contact time for disinfection. stores water for high demand.
Finished Water	

Fig. 1.1 Flow diagram of conventional surface water treatment plant processes

Raw water usually enters a water treatment plant through some type of intake structure. The main purpose of the intake structure is to draw in water while preventing leaves and other debris from clogging or damaging pumps, pipes and other pieces of equipment in the treatment plant. Various types of screens are often found in intake structures or in the suction line to raw water pumps.

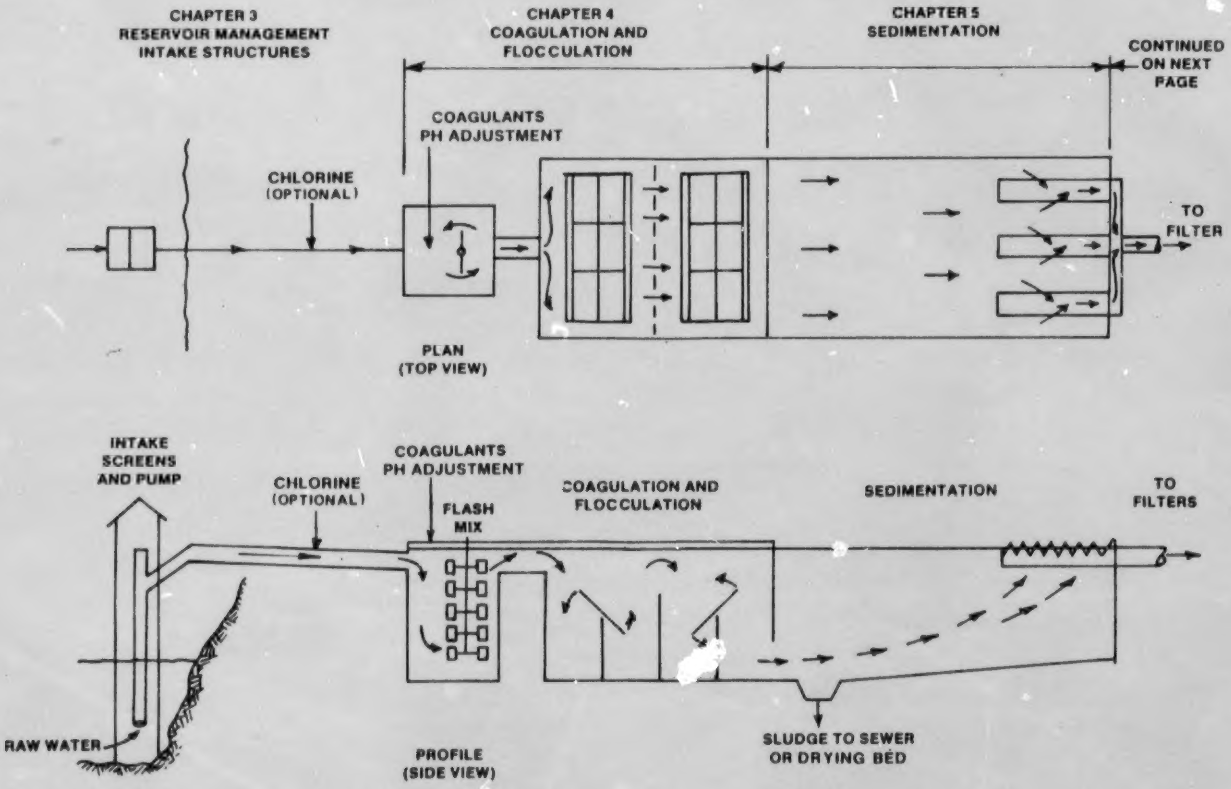


Chlorination at the beginning of a water treatment plant (prechlorination) can help control tastes and odors and also prevent the growth of algae and slimes in other treatment processes. Chlorine is added to water to kill pathogenic (disease-causing) organisms. Also, the use of prechlorination often reduces chlorine requirements for postchlorination. Some waters should not be prechlorinated because they contain substances which will react with chlorine and form cancer-causing compounds (trihalomethanes).

Coagulant chemicals such as alum are added to help remove light, fine particles and other materials suspended in the water. Coagulants cause these very fine particles to clump together into larger particles. A flash mixer is used to thoroughly mix the coagulating chemicals with the water being treated. Flocculation is the name of the treatment process where paddles gently mix the water. The clumps of particles formed by coagulation come together and form larger and larger floc particles. These larger floc particles are easier to remove by sedimentation and filtration.

Sedimentation is an operation in which the water being treated flows very slowly through a large tank or basin. During this time the heavier floc particles gradually settle out of the water being treated. The flocs and settled solids that reach the bottom of the basin form a sludge that must be removed and either discharged to a sewer or disposed of in a landfill after drying beds. Treated water leaves the sedimentation basin by flowing over weirs (a flow control device) at the outlet end of the basin.

After sedimentation, the water passes through some type of filter to remove the remaining suspended impurities and flocs. The filter may be made of sand, anthracite coal or some other type of granular material or a combination of these materials.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RAW WATER
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SLUDGE TO SEWER OR DRYING BED

Fig. 1.2 Flow pattern through a conventional surface water treatment plant

After filtration the water is usually disinfected by some type of chlorination process. The purpose of disinfection is to kill the remaining disease-causing organisms in the water.

If the treated water is corrosive (capable of deteriorating metal pipe), chemicals should be added to reduce the corrosivity of the water or to prevent scale (rust) formation.

Treated water is stored in a large tank or basin (clear well) until it is pumped into the distribution system for use or to service storage during low demand periods for later use during periods of high demand. Storage also provides chlorine contact time for disinfection.

1.11 Softening

Some water treatment plants include processes for softening water. Waters are softened to remove excess hardness caused by calcium and magnesium. Extra soap is needed to clean or wash with hard water. Also hard waters will cause scale to develop in water heaters, pipes, and fittings.

1.12 Iron and Manganese Control

Iron and manganese are undesirable because they will cause undesirable color in water and also stain clothes and plumbing fixtures. Iron and manganese also can promote the growth of iron bacteria which can cause tastes and odors. Flow diagrams and treatment processes for removing hardness and also iron and manganese will be discussed in Volume II of this manual.

All of the chapters in Volume I of this manual deal with the processes shown in Figures 1.1 and 1.2. As you go through this manual, feel free to return to these figures so you will understand the location and purposes of these processes and how they relate to each other. *REMEMBER* that if the quality of the raw water changes, or any process fails to do its intended job, all of the downstream processes will be affected.

QUESTIONS

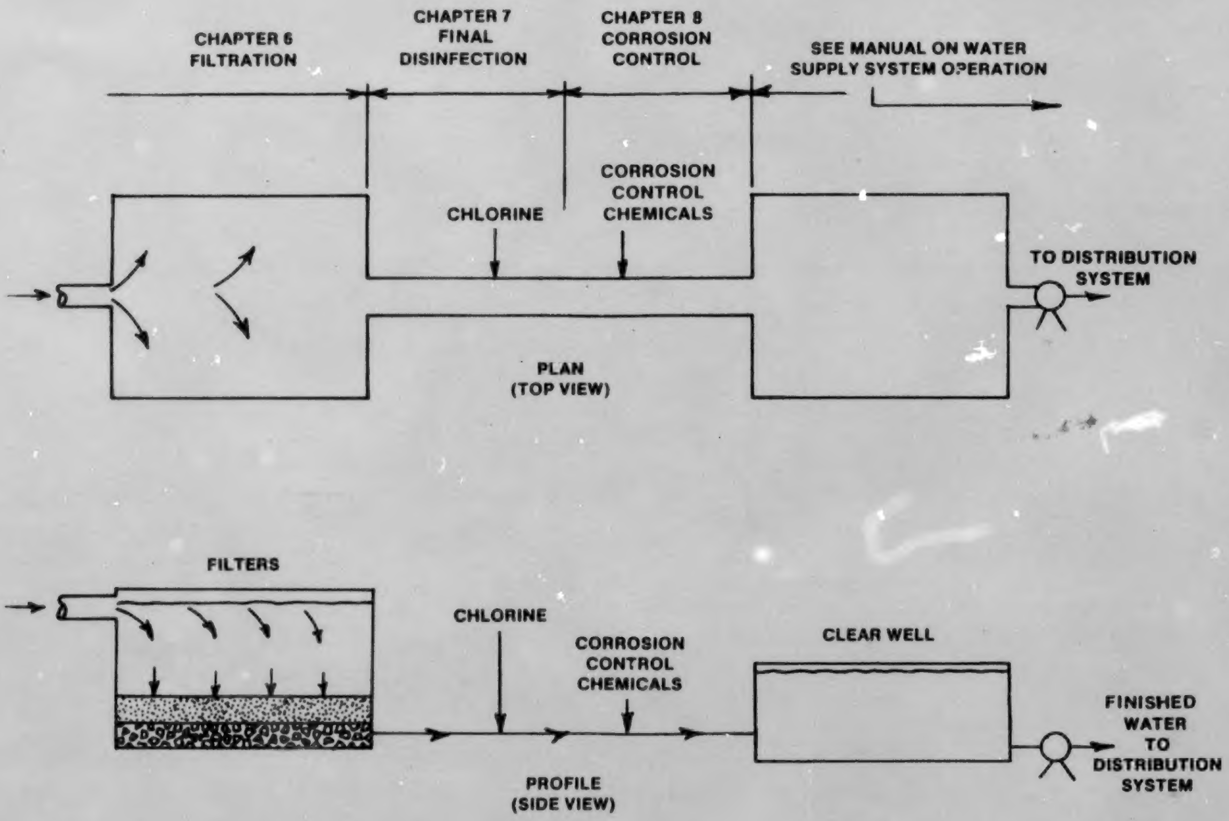
Write your answers in a notebook and then compare your answers with those on page 11.

1.1A What is the purpose of a water treatment plant?

1.1B Why do intake structures at water treatment plants have screens?

1.1C How is the sludge disposed of after it is removed from a sedimentation basin?

1.1D Why is excessive hardness removed from drinking water?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FILTRATION
CHAPTER 7
FINAL
DISINFECTION
CHAPTER 8
CORROSION
CONTROL
SEE MANUAL ON WATER
SUPPLY SYSTEM OPERATION
CHLORINE
CORROSION
CONTROL
CHEMICALS
TO DISTRIBUTION
SYSTEM
PLAN
(TOP VIEW)
FILTERS
CHLORINE
CORROSION
CONTROL
CHEMICALS
CLEAR WELL
FINISHED
WATER
TO
DISTRIBUTION
SYSTEM
PROFILE
(SIDE VIEW)

Fig. 1.2 Flow pattern through a conventional surface water treatment plant (continued)

1.2 WHAT DOES A WATER TREATMENT PLANT OPERATOR DO?

1.20 Operation and Maintenance

Simply described, water treatment plant operators keep a treatment plant operating to produce a safe, pleasant, and adequate supply of water. They monitor the raw water entering the plant and keep an eye on the water as it flows through all of the various treatment processes. Flows into the plant are adjusted according to conditions of the raw water and system demands for water. Equipment and facilities are maintained and repaired as necessary to keep the water flowing and the plant working today and into the future. Typical duties performed by water treatment plant operators are summarized in Table 1.1

To start at the beginning, let's assume that the need for a new or improved water treatment plant has been recognized by the community. The community has voted to issue the necessary bonds to finance the project, and the consulting engineers have been requested to submit plans and specifications. In the best interests of the community and the consulting engineer, you should be present (or at least available) during both the design and construction periods in order to be completely familiar with the entire plant layout, including the piping, equipment, and machinery and their intended operation. This will provide you with the opportunity to relate your plant drawings to actual facilities. At this time you should gather together all the data and literature for the equipment in order to prepare a regular maintenance schedule. You and the engineer should discuss how the water treatment plant should best be run and the means of operation the designer had in mind when the plant was designed.

If the plant is an old one that is being remodeled, you may be in a position to offer excellent advice to the consulting engineer. Your experience provides valuable technical knowledge concerning the characteristics of the raw water and the limitations of the present facilities. Together with the consultant, you can be a member of an expert team able to advise your water utility.

1.21 Supervision and Administration

In addition to operation and maintenance duties for your water treatment plant, you may also be responsible for supervision of personnel. Chief operators frequently have the responsibility of training new operators and should encourage all operators to strive for higher levels of certification.

As a plant administrator, you may be in charge of recordkeeping. In this case, you will be responsible for operating and maintaining the facilities as efficiently as possible, keeping in mind that the primary objective is to produce safe and pleasant drinking water from your plant. Without adequate, reliable records of the important phases of operation and maintenance, the effectiveness of your operation will not be properly documented (recorded). Also, accurate records are required by regulating agencies in accordance with the Interim Primary Drinking Water Regulations of the Safe Drinking Water Act.

Records are an excellent operating tool. Reference to past records can be quite helpful in adjusting treatment processes for various changes in raw water.

You may also be the budget administrator. Here you will be in the best position to give advice on budget requirements, management problems, and future planning. You should be aware of the necessity for additional expenditures, including funds for plant maintenance and enlargement, equipment replacement, laboratory requirements, and personnel needs. You should recognize and define such needs in sufficient time to inform the proper officials to enable them to accomplish early planning and budgeting.

1.22 Public Relations

As an operator, you are in the field of public relations and must be able to explain the purpose and operation of your water treatment plant to visitors, civic organizations, school classes, representatives of the news media, and even to city council members or directors of your district. A well-guided tour for officials of regulatory agencies or other operators may provide these people with sufficient understanding of

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Table 1.1 TYPICAL DUTIES OF A WATER TREATMENT PLANT OPERATOR

1. Start up, shut down and make periodic operating checks of plant equipment, such as pumping systems, chemical feeders, auxiliary equipment (compressors), measuring and control systems.
2. Perform routine preventive maintenance, such as lubrication, operating adjustments, cleaning and painting equipment.
3. Load and unload chemicals, such as chlorine cylinders, bulk liquids, powdered chemicals and bagged chemicals using chemical-handling equipment such as fork lifts, hoists, and by hand.
4. Perform minor corrective maintenance on plant mechanical equipment, for example, chemical feed pumps and small units.
5. Maintain plant records, including operating logs, daily dairies, chemical inventories and data logging duties.
6. Monitor the status of plant operating guidelines, such as flows, pressures, chemical feeds, levels, and water quality indicators by reference to measuring systems.
7. Collect representative water samples and perform laboratory tests on samples for turbidity, color, odor, coliforms, chlorine residual, and other tests as required.
8. Order chemicals, repair parts and tools.
9. Estimate and justify budget needs for equipment and supplies.
10. Conduct safety inspections, follow safety rules for plant operations, and also develop and conduct tailgate safety meetings.
11. Discuss water quality with the public, conduct tours of your plant (especially school children), and participate in your employer's public relations program.
12. Communicate effectively with other operators and supervisors on the technical level expected for your position.
13. Make arithmetic calculations to determine chemical feed rates, flow quantities, detention and contact times, and hydraulic loadings as required for plant operations.

your plant to allow them to suggest helpful solutions to operational problems. One of the best results from a well-guided tour is gaining support from your city council and the public to obtain the funds necessary to run a good operation.

The overall appearance of your water treatment plant indicates to visitors the type of operation you maintain. If the plant looks dirty and run down, you will be unable to convince your visitors that you are doing a good job. *YOUR RECORDS SHOWING THAT YOU ARE PRODUCING A SAFE DRINKING WATER WILL MEAN NOTHING TO VISITORS UNLESS YOUR PLANT APPEARS CLEAN AND WELL MAINTAINED.*

Another aspect of your job may be handling complaints. When someone contacts you complaining that their drinking water looks muddy, tastes bad or smells bad, you have a serious problem. Whenever someone complains, record all of the necessary information (name, date, location, and phone number) and have the complaint thoroughly investigated. Be sure to notify the person making the complaint of the results of your investigation and what corrective action was or will be taken.

1.23 Safety

Safety is a very important operator responsibility. Unfortunately, too many operators take safety for granted. *YOU* have the responsibility to be sure that your water treatment plant is a safe place to work and visit. Everyone must follow safe procedures and understand why safe procedures must be followed at all times. All operators must be aware of the safety hazards in and around treatment plants. Most accidents result from carelessness or negligence. You should plan or be a part of an active safety program. Chief operators frequently have the responsibility of training new operators and safe procedures must be stressed.

Clearly, the modern day water treatment plant operator must be capable of doing many jobs — *AND DOING THEM ALL SAFELY!*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 11.

1.2A Why should a water treatment plant operator be present when a new plant is being constructed?

1.2B What is the reason for keeping adequate, reliable records?

1.2C Why are well-guided tours for officials of regulatory agencies or other operators important?

1.2D Why is safety important?

1.3 JOB OPPORTUNITIES

1.30 Manpower Needs

The water treatment field is changing rapidly. New treatment plants are being constructed, and old plants are being modified and enlarged to meet the water demands of our growing population and industries. Towns, municipalities, special districts, and industries all employ water treatment plant operators. Operators, maintenance personnel, foremen, managers, instrumentation experts, and laboratory technicians are sorely needed now and will be into the future.

1.31 Who Hires Water Treatment Plant Operators?

Operators' paychecks usually come from a city, water agency or district, or a private utility company. The operator also may be employed by one of the many large industries which operate their own water treatment facilities. As an operator, you are always responsible to your employer for operating and maintaining an economical and efficient water treatment plant. An even greater obligation rests with the operator because of the great number of people who drink the water from the water treatment plant. In the final analysis, the operator is really working for the people who depend on the operator to produce safe and pleasant drinking water from the treatment plant.

1.32 Where Do Water Treatment Plant Operators Work?

Jobs are available for water treatment plant operators wherever people live and need someone to treat water for their homes, offices or industrial processes. The different types and locations of water treatment plants offer a wide range of working conditions. From the mountains to the seas, wherever people gather together into communities, water treatment plants will be found. From a single process operator or a computer control center operator at a complex municipal treatment plant to a one-person manager of a small town water treatment plant, you can select your own special place in water treatment plant operation.

1.33 What Pay Can A Water Treatment Plant Operator Expect?

In dollars? Prestige? Job satisfaction? Community service? In opportunities for advancement? By whatever scale you use, returns are mainly what you make them. If you choose a large municipality, the pay is good and advancement prospects are tops. Choose a small town and the pay may not be as good, but job satisfaction, freedom from time-clock hours, community service, and prestige may well add up to a more desirable outstanding personal achievement. If you have the ability and take advantage of the opportunities, you can make this field your career and advance to an enviable position. Many of these positions are or will be represented by an employee organization that will try to obtain higher pay and other benefits for you. Total reward depends on you and how *YOU APPLY YOURSELF.*

1.34 What Does It Take To Be A Treatment Plant Operator?

DESIRE. First you must make the serious decision to enter this fine profession. You can do this with a high school or a college education. While some jobs will always exist for manual labor, the real and expanding need is for *QUALIFIED OPERATORS.* You must be willing to study and take an active role in upgrading your capabilities. New techniques, advanced equipment, and increasing use of complex instrumentation and computers require a new breed of water treatment plant operator: one who is willing to learn today, and gain tomorrow, for surely your water treatment plant will move towards newer and more effective operation and maintenance procedures. Indeed, the truly service-minded operator assists in adding to and improving the performance of the water treatment plant on a continuing basis.

You can be a water treatment plant operator tomorrow by beginning your learning today; or you can be a better operator, ready for advancement, by accelerating your learning today.

This training course, then, is your start towards a better tomorrow, both for you and for the public who will receive better water from your efforts.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 11.

1.3A Who hires water treatment plant operators?

1.3B What does it take to be a good water treatment plant operator?

1.4 PREPARING YOURSELF FOR THE FUTURE

1.40 Your Qualifications

What do you know about your job or the job you'd like to obtain? Perhaps a little, and perhaps a lot. You must evaluate the knowledge, skills and experience you already have and what you will need to achieve future jobs and advancement.

The knowledge and skills required for your job depend to a large degree on the size and type of water treatment plant where you work. You may work in a large, complex water treatment plant serving several hundred thousand persons and employing 15 to 25 operators.

On the other hand, you may operate and maintain a small water treatment plant serving only a thousand people or even fewer. You may be the only operator and have other duties or, at best, you may have one or two helpers. If this is the case, you must be a "jack-of-all-trades" because of the diversity of your tasks.

1.41 Your Personal Training Program

Beginning on this page you are starting a training course which has been carefully prepared to help you to improve your knowledge and skills to operate and maintain water treatment plants.

OPPORTUNITY

You will be able to proceed at your own pace; you will have the opportunity to learn a little or a lot about each topic. This training manual has been prepared this way to meet the various needs of water treatment plant operators, depending on the size and type of plant for which you are responsible. To study for certification and civil service exams, you may have to cover most of the material in both Volumes I and II. You will never know everything about water treatment plants and the equipment, processes and procedures available for operation and maintenance. However, you will be able to answer some very important questions about how, why, and when certain things happen in these plants. You can also learn how to manage your water treatment plant to produce a reliable output of safe and pleasant drinking water for your customers while minimizing costs in the long run.

This training course is not the only one available to help you improve your abilities. Some state water utility associations, vocational schools, community colleges, and universities offer training courses on both a short- and long-term basis. Many state, local and private agencies have conducted training programs and informative seminars. Most state health departments can be very helpful in providing training programs or directing you to good programs.

Some libraries can provide you with useful journals and books on water treatment. Listed below are several very good references in the field of water treatment. Prices listed were those available when this manual was published; they will probably increase in the future.

1. *A MANUAL OF INSTRUCTION FOR WATER TREATMENT PLANT OPERATORS.* Available from Health Education Service, Inc., P.O. Box 7126, Albany, New York 12224. Price $3.13.
2. *MANUAL OF WATER UTILITY OPERATIONS.* Available from Texas Water Utilities Association, 6521 Burnet Lane, Austin, Texas 78757. Price $17.00.
3. *BASIC WATER TREATMENT OPERATIONS,* Ministry of Environment, Ministry of Government Services, Publication Center, 880 Bay Street, Fifth Floor, Toronto, Ontario M7A 1N8, CANADA. Price $4.50 payable to Treasurer of Ontario.
4. *STUDY GUIDE TO THE ABC TESTING SERVICE FOR WATER TREATMENT PLANT AND DISTRIBUTION SYSTEM OPERATORS,* Association of Boards of Certification (ABC), P.O. Box 2266, Ames, Iowa 50010. Price $14.00.
5. *INTRODUCTION TO WATER TREATMENT,* Volume 2, Order No. 19XX. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to be determined. Available 1983.
6. *INTRODUCTION TO WATER QUALITY ANALYSIS,* Volume 4, Order No. 1931. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price $11.00.

7. *BASIC SCIENCE CONCEPTS AND APPLICATIONS. REFERENCE HANDBOOK*, Order No. 1940. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price $24.00.

Throughout this manual we will be recommending American Water Works Association (AWWA) publications. Members of AWWA can buy some publications at reduced prices. You can join AWWA by writing to the headquarters office in Denver or by contacting a member of AWWA. Headquarters can help you contact your own state or regional AWWA Section. This professional organization can offer you many helpful training opportunities and educational materials when you join and actively participate with your associates in the field.

1.42 Certification

Certification examinations are usually administered by state regulatory agencies or professional associations. Operators take these exams in order to obtain certificates which indicate a level of professional competence. You should continually strive to achieve higher levels of certification. Successful completion of this operator training program will help you achieve your certification goals.

1.5 ACKNOWLEDGMENTS

Many of the topics and ideas discussed in this chapter were based on similar work written by Larry Trumbull and Walt Driggs.

SUGGESTED ANSWERS

Chapter 1. THE WATER TREATMENT PLANT OPERATOR

You are not expected to have the exact answer suggested for questions requiring written answers, but you should have the correct idea. The numbering of the questions refers to the section in the chapter where you can find the information to answer the questions. Answers to questions number 1.0A and 1.0B can be found in Section 1.0, "Need for Water Treatment Plant Operators."

Answers to questions on page 4.

1.0A Water treatment plant operators are needed to operate, maintain, repair and manage the water treatment plants that provide us with safe drinking water.

1.0B Many sources of water need treatment because they have been polluted and contaminated by man and nature and are not directly suitable for drinking.

1.0C Water treatment plant operators must be responsible persons because they are responsible for the health and well being of the community they serve.

Answers to questions on page 7.

1.1A The purpose of a water treatment plant is to produce safe and pleasant drinking water.

1.1B Intake structures at water treatment plants have screens to prevent leaves and other debris from clogging or damaging pumps, pipes and other pieces of equipment in the treatment plant.

1.1C Sludge removed from a sedimentation basin is disposed of by discharge to a sewer or is dried and then disposed of in a landfill or on land.

1.1D Excessive hardness is removed from drinking water because hardness requires extra soap to clean or wash and may cause scale to develop in water heaters, pipes and fittings.

Answers to questions on page 9.

1.2A A water treatment plant operator should be present when a new plant is being constructed in order to be completely familiar with the entire plant layout, including the piping, equipment, and machinery and their intended operation.

1.2B Adequate, reliable records are important to document (record) the effectiveness of your operation and are required by regulatory agencies.

1.2C Well-guided tours for officials of regulatory agencies or other operators may provide these people with sufficient understanding of your plant to allow them to suggest helpful solutions to operational problems. Also well-guided tours will help gain the funds necessary to run a good operation.

1.2D Safety is a very important operator responsibility. Most accidents result from carelessness or negligence. Safe procedures must be stressed at all times.

Answers to questions on page 10.

1.3A Water treatment plant operators may be hired by cities, water agencies or districts, private utility companies, or industries.

1.3B *DESIRE.* If you want to be a qualified water treatment plant operator, you can do it.

WATER TREATMENT PLANT OPERATION

IMPORTANT

PLEASE READ INSTRUCTIONS ON REVERSE SIDE BEFORE COMPLETING THIS FORM.

OFFICE USE ONLY
DO NOT MARK
●

Name: OPERATOR, JOE B
Last First MI

Address: 711 MAIN ST

SAFEWATER CA 01234
City State Zip Code

SOCIAL SECURITY NUMBER									CHAPTER NUMBER	
1	2	3	4	5	6	7	8	9		
⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	●	⓪
●	①	①	①	①	①	①	①	①	①	●
②	●	②	②	②	②	②	②	②	②	②
③	③	●	③	③	③	③	③	③	③	③
④	④	④	●	④	④	④	④	④		④
⑤	⑤	⑤	⑤	●	⑤	⑤	⑤	⑤		⑤
⑥	⑥	⑥	⑥	⑥	●	⑥	⑥	⑥		⑥
⑦	⑦	⑦	⑦	⑦	⑦	●	⑦	⑦		⑦
⑧	⑧	⑧	⑧	⑧	⑧	⑧	●	⑧		⑧
⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	●		⑨

Mail to: Professor Kenneth Kerri
California State University, Sacramento
6000 Jay Street
Sacramento, California 95819

FOLD

IMPORTANT DIRECTIONS FOR MARKING ANSWERS

Use black lead pencil only (# 2 or softer).
Make heavy black marks that fill the circle completely.
Erase clearly any answer you wish to change.
Make no stray marks on this answer sheet.

EXAMPLE

SOCIAL SECURITY NUMBER									CHAPTER NUMBER	
1	2	3	4	5	6	7	8	9	0	1
⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	⓪	●	⓪
●	①	①	①	①	①	①	①	①	①	●
②	●	②	②	②	②	②	②	②	②	②
③	③	●	③	③	③	③	③	③	③	③
④	④	④	●	④	④	④	④	④		④
⑤	⑤	⑤	⑤	●	⑤	⑤	⑤	⑤		⑤
⑥	⑥	⑥	⑥	⑥	●	⑥	⑥	⑥		⑥
⑦	⑦	⑦	⑦	⑦	⑦	●	⑦	⑦		⑦
⑧	⑧	⑧	⑧	⑧	⑧	⑧	●	⑧		⑧
⑨	⑨	⑨	⑨	⑨	⑨	⑨	⑨	●		⑨

1. MULTIPLE CHOICE QUESTIONS: Fill in the correct answers. If 2 and 3 are correct for question 1, mark:

   1 2 3 4 5
   1 Ⓣ ● ● ○ ○

2. TRUE–FALSE QUESTIONS: If true, fill in the circle in column 1; if false, fill in column 2. If question 3 is true, mark:

   1 2 3 4 5
   3 ● Ⓕ ○ ○ ○

SAMPLE

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2 Ⓣ Ⓕ ○ ○ ○	12 Ⓣ Ⓕ ○ ○ ○	22 Ⓣ Ⓕ ○ ○ ○	32 Ⓣ Ⓕ ○ ○ ○	42 Ⓣ Ⓕ ○ ○ ○	52 Ⓣ Ⓕ ○ ○ ○
3 Ⓣ Ⓕ ○ ○ ○	13 Ⓣ Ⓕ ○ ○ ○	23 Ⓣ Ⓕ ○ ○ ○	33 Ⓣ Ⓕ ○ ○ ○	43 Ⓣ Ⓕ ○ ○ ○	53 Ⓣ Ⓕ ○ ○ ○
4 Ⓣ Ⓕ ○ ○ ○	14 Ⓣ Ⓕ ○ ○ ○	24 Ⓣ Ⓕ ○ ○ ○	34 Ⓣ Ⓕ ○ ○ ○	44 Ⓣ Ⓕ ○ ○ ○	54 Ⓣ Ⓕ ○ ○ ○
5 Ⓣ Ⓕ ○ ○ ○	15 Ⓣ Ⓕ ○ ○ ○	25 Ⓣ Ⓕ ○ ○ ○	35 Ⓣ Ⓕ ○ ○ ○	45 Ⓣ Ⓕ ○ ○ ○	55 Ⓣ Ⓕ ○ ○ ○
6 Ⓣ Ⓕ ○ ○ ○	16 Ⓣ Ⓕ ○ ○ ○	26 Ⓣ Ⓕ ○ ○ ○	36 Ⓣ Ⓕ ○ ○ ○	46 Ⓣ Ⓕ ○ ○ ○	56 Ⓣ Ⓕ ○ ○ ○
7 Ⓣ Ⓕ ○ ○ ○	17 Ⓣ Ⓕ ○ ○ ○	27 Ⓣ Ⓕ ○ ○ ○	37 Ⓣ Ⓕ ○ ○ ○	47 Ⓣ Ⓕ ○ ○ ○	57 Ⓣ Ⓕ ○ ○ ○
8 Ⓣ Ⓕ ○ ○ ○	18 Ⓣ Ⓕ ○ ○ ○	28 Ⓣ Ⓕ ○ ○ ○	38 Ⓣ Ⓕ ○ ○ ○	48 Ⓣ Ⓕ ○ ○ ○	58 Ⓣ Ⓕ ○ ○ ○
9 Ⓣ Ⓕ ○ ○ ○	19 Ⓣ Ⓕ ○ ○ ○	29 Ⓣ Ⓕ ○ ○ ○	39 Ⓣ Ⓕ ○ ○ ○	49 Ⓣ Ⓕ ○ ○ ○	59 Ⓣ Ⓕ ○ ○ ○
0 Ⓣ Ⓕ ○ ○ ○	20 Ⓣ Ⓕ ○ ○ ○	30 Ⓣ Ⓕ ○ ○ ○	40 Ⓣ Ⓕ ○ ○ ○	50 Ⓣ Ⓕ ○ ○ ○	60 Ⓣ Ⓕ ○ ○ ○

DIRECTIONS FOR WORKING OBJECTIVE TEST

Chapter 1. THE WATER TREATMENT PLANT OPERATOR

1. You have been provided with a special answer sheet for each chapter. Be sure you follow the special directions provided with the answer sheets. If you lose an answer sheet or have any problems, please notify the Project Director.

2. Mark your answers on the answer sheet with a dark lead pencil. Do not use ink.

   For example, if Questions 2 had three correct answers (1, 2 and 3), you should place a mark under Columns 1, 2 and 3 on the answer sheet.

   Questions 1 through 5 are true or false questions. If a question is true, then mark Column 1, and if false, mark Column 2. The correct answer to Question 4 is true; therefore, place a mark in Column 1.

   Please mark your answers in your workbook for your record because answer sheets will not be returned to you.

3. Mail answer sheet to the Project Director immediately after you have completed the test.

4. Answer sheets may be folded (but not into more than 3 equal parts) and mailed in a 4 x 9½ standard white envelope to:

   Ken Kerri, Project Director
   Water Treatment Plant Operation
   California State University, Sacramento
   6000 J Street
   Sacramento, California 95819

OBJECTIVE TEST

Chapter 1. THE WATER TREATMENT PLANT OPERATOR

Please mark the correct answers on an answer sheet as directed at the end of Chapter 1. There may be more than one correct answer in the multiple choice questions.

True-False

1. Safety is not the operator's responsibility, but the responsibility of the supervisor.
   1. True
   2. False

2. Plant visitors are impressed by records showing efficient operation, and their opinions are seldom influenced by the appearance of the plant and grounds.
   1. True
   2. False

3. After finishing this program, you will not have to study water treatment any more.
   1. True
   2. False

4. In many water treatment plants the operator must be a "jack-of-all-trades."
   1. True
   2. False

5. Excessive hardness is removed from waters to prevent the staining of clothes and plumbing fixtures.
   1. True
   2. False

Multiple Choice

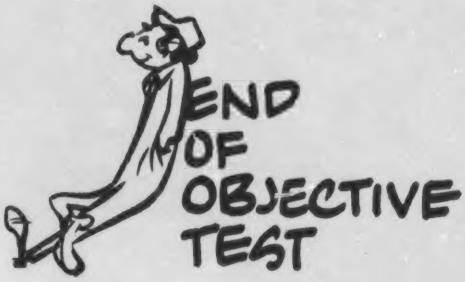
6. The purpose of a water treament plant is to produce water free of
   1. Disagreeable tastes.
   2. Disease-causing organisms.
   3. Toxic substances.
   4. Undesirable odors.
   5. Unpleasant appearances.

7. The *MAIN* purpose of flocculation is to
   1. Filter out suspended particles.
   2. Gather together fine particles to form larger particles.
   3. Mix chemicals with raw water containing fine particles.
   4. Reduce corrosivity of treated water.
   5. Settle out suspended particles.

8. Screens are installed in intake structures to remove _____ from the raw water.
   1. Debris
   2. Dissolved solids
   3. Fine particles
   4. Leaves
   5. Suspended solids

9. Water treatment plant operators are responsible for
   1. Keeping accurate records.
   2. Maintaining the appearance of their plant.
   3. Protecting the health and well being of the community.
   4. Safely performing their job.
   5. Teaching school children.

10. An experienced water treatment plant operator may be expected to
    1. Develop a safety program.
    2. Maintain equipment.
    3. Operate treatment processes.
    4. Respond to complaints.
    5. Train new operators.



Chapter 2

WATER SOURCES AND TREATMENT

by

Bert Ellsworth

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OBJECTIVES

Chapter 2. WATER SOURCES AND TREATMENT

Following completion of Chapter 2, you should be able to:

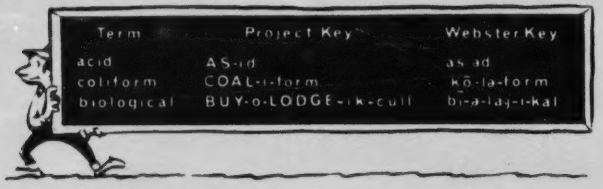
1. Describe the importance of water,
2. Identify various sources of water,
3. Outline the procedures of a sanitary survey,
4. Evaluate the suitability of a water source for drinking purposes and as a general water supply, and
5. Identify water quality problems and treatment processes to solve the problems.

OPERATOR'S PROJECT PRONUNCIATION KEY

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this Key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This Key is designed solely to aid operators in this program.

You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation Key. Each Key will be different from each other and from this Key. Examples of the differences between the Key used in this program and the *WEBSTER'S NEW WORLD DICTIONARY* "Key" are shown below:



Term	Project Key	Webster Key
acid	AS-id	as ad
coliform	COAL-i-form	kō-la-form
biological	BUY-o-LODGE-ik-cull	bi-a-laj-i-kal

In using this Key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	Syllable				
	1st	2nd	3rd	4th	5th
Word					
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word *ACID* has its first syllable accented. The second word, *COAGULANT*, has its second syllable accented. The third word, *BIOLOGICAL*, has its first and third syllables accented.

We hope you will find the Key useful in unlocking the pronunciation of any new word.

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[1] *The WEBSTER'S NEW WORLD DICTIONARY, Second College Edition, 1972, was chosen rather than an unabridged dictionary because of its availability to the operator. Other editions may be slightly different.*

GLOSSARY

Chapter 2. WATER SOURCES AND TREATMENT

ACID RAIN ACID RAIN

Precipitation which has been rendered (made) acidic by airborne pollutants.

APPROPRIATIVE APPROPRIATIVE

Water rights to or ownership of a water supply which is acquired for the beneficial use of water by following a specific legal procedure.

AQUIFER (ACK-wi-fer) AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

ARTESIAN (are-TEE-zhun) ARTESIAN

Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given the opportunity to do so.

CAPILLARY FRINGE CAPILLARY FRINGE

The porous material just above the water table which may hold water by capillarity (a property of surface tension that draws water upwards) in the smaller void spaces.

CISTERN (SIS-turn) CISTERN

A small tank (usually covered) or a storage facility used to store water for a home or farm.

CONTAMINATION CONTAMINATION

The introduction into water of microorganisms, chemicals, toxic materials, wastes or wastewater in a concentration that makes the water unfit for its next intended use.

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

DIRECT RUNOFF DIRECT RUNOFF

Water that flows over the ground surface or through the ground directly into streams, rivers, or lakes.

DRAWDOWN DRAWDOWN

The drop in the water table or level of water in the ground when water is being pumped from the well.

EPIDEMIOLOGY (EP-uh-DEE-me-ALL-o-gee) EPIDEMIOLOGY

A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.

EVAPORATION EVAPORATION

The process by which water or other liquid becomes a gas (water vapor or ammonia vapor).

EVAPOTRANSPIRATION (ee-VAP-o-TRANS-purr-A-shun) EVAPOTRANSPIRATION

The process by which water vapor passes into the atmosphere from living plants. Also called TRANSPIRATION.

GEOLOGICAL LOG GEOLOGICAL LOG

A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).

HYDROLOGIC CYCLE (HI-dro-LOJ-ic) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE.

IMPERMEABLE (im-PURR-me-uh-BULL) IMPERMEABLE

Not easily penetrated. The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water.

INFILTRATION (IN-fill-TRAY-shun) INFILTRATION

The gradual flow or movement of water into and through (to percolate or pass through) the pores of the soil. Also called PERCOLATION.

MICROORGANISMS (MY-crow-OR-gan-IS-zums) MICROORGANISMS

Living organisms that can be seen individually only with the aid of a microscope.

NONPOTABLE (non-POE-tuh-bull) NONPOTABLE

Water that may contain objectionable pollution, contamination, minerals, or infective agents and is considered unsafe and/or unpalatable for drinking.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desired temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PATHOGENIC ORGANISMS (path-o-JEN-nick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of organisms which do *NOT* cause disease. These organisms are called non-pathogenic.

POLLUTION POLLUTION

The impairment (reduction) of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes), to a degree that has an adverse effect on any beneficial use of water.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

PRECIPITATION (pre-SIP-i-TAY-shun) PRECIPITATION

The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, and other forms of moisture.

PRESCRIPTIVE (pre-SKRIP-tive) PRESCRIPTIVE

Water rights which are acquired by diverting water and putting it to use in accordance with specified procedures. These procedures include the filing of a request to use unused water in a stream, river or lake with a state agency.

RAW WATER RAW WATER

(1) Water in its natural state, prior to any treatment.
(2) Usually the water entering the first treatment process of a water treatment plant.

RIPARIAN (ri-PAIR-i-an) RIPARIAN

Water rights which are acquired together with title to the land bordering a source of surface water. The right to put to beneficial use surface water adjacent to your land.

SAFE DRINKING WATER ACT (SDWA) SAFE DRINKING WATER ACT (SDWA)

Commonly referred to as SDWA. An Act passed by the US Congress in 1974. The Act establishes a cooperative program among local, state and federal agencies to insure safe drinking water for consumers.

SAFE WATER SAFE WATER

Water that does not contain harmful bacteria, or toxic materials or chemicals. Water may have taste and odor problems, color and certain mineral problems and still be considered safe for drinking.

SAFE YIELD
SAFE YIELD

The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source permanently (beyond its ability to be replenished naturally in "wet years").

SANITARY SURVEY
SANITARY SURVEY

A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, treatment and distribution facilities to insure its protection from all pollution sources.

SEWAGE
SEWAGE

The used water and solids from homes that flow through sewers to a wastewater treatment plant. The preferred term is WASTEWATER.

SHORT-CIRCUITING
SHORT-CIRCUITING

A usually undesirable condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This results in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

STRATIFICATION (STRAT-uh-fuh-KAY-shun)
STRATIFICATION

The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature.

TOPOGRAPHY
TOPOGRAPHY

The arrangement of hills and valleys in a geographic area.

TRANSPIRATION (TRAN-spur-RAY-shun)
TRANSPIRATION

The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.

TRIHALOMETHANES (tri-HAL-o-METH-hanes)
TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with organic materials. The resulting compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee)
TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY UNITS (TU)
TURBIDITY UNITS

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

WASTEWATER
WASTEWATER

The used water and solids from a community (including used water from industrial processes) that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a wastewater treatment plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "wastewater."

WATER TABLE
WATER TABLE

The upper surface of the zone of saturation of groundwater in an unconfined aquifer.

YIELD
YIELD

The quantity of water (expressed as a rate of flow — GPM, GPH, GPD or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. Also see SAFE YIELD.

ZONE OF AERATION | ZONE OF AERATION

The comparatively dry soil or rock located between the ground surface and the top of the water table.

ZONE OF SATURATION | ZONE OF SATURATION

The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.

are-TEE-shun

CHAPTER 2. WATER SOURCES AND TREATMENT

2.0 IMPORTANCE OF WATER

For decades Americans have used water as though their supply would never fail. In recent years, drought conditions have forceably brought the need to conserve and properly budget our water resources to the minds of water supply managers. Even in the driest years, though, rain across the country enormously exceeds water use. The trouble is that the nation's water resources are poorly distributed. The Pacific Northwest has a big surplus. The agricultural states of the Southwest fight for the last salty drop of water from the Lower Colorado River. The Federal Government has spent billions of dollars building and operating facilities to divert water for use in arid and water-short areas. Contamination is a problem, too. Mineral residues from irrigation have damaged once fertile soil. *ACID RAIN*[1] is killing the fish in mountain lakes. America's drinking water has been tainted with substances as exotic as trichloroethylene (TCE) and as commonplace as highway salt. Vast underground basins of water, deposited over many years, have been seriously depleted in a matter of decades.

All water comes as rain or precipitation from the sky, but 92 percent of the water either evaporates immediately or runs off eventually into the oceans. One-quarter of the water that irrigates, powers and bathes America is taken from an ancient network of underground aquifers. In 1950, the United States took some 12 trillion gallons (45 billion cubic meters) of water out of the ground; by 1980 the figure had more than doubled.

The energy crisis and water shortages are linked together. As groundwater levels fall, more energy is required to pump water from deeper levels in the basin. In several areas, vast water projects use large amounts of electricity to pump water many miles along the project. As energy becomes more expensive, the users of the water will see the increased cost reflected in their water rates.

Water is regarded as commonplace because it is the most plentiful liquid on earth and because of our familiarity with it. All of the tissues of our bodies are bathed in it. Whatever may be the thing which we call life on earth, it requires a water environment. Our foods must be suspended or dissolved in water solutions to be carried to the different parts of the body. Also, most waste products are eliminated from the body as water-soluble substances.

Both plant life and animal life depend upon water for survival. A plant receives the greater part of its food from the soil in water solutions and manufactures the rest of its food in the presence of water.

Water is present in almost all natural objects and in almost every part of the earth that people can reach. There is water vapor in the air, and liquid water in rocks and soil. In addition to the water that wets them, clay and certain kinds of rocks contain water in chemical combination with other substances.

Water may be commonplace, but useful water is not always readily available. Even before the discovery of America, one of the common causes of war between Indian tribes was water rights. Among the first considerations of any new land development is water. Useful water is only rarely free, and it is not very abundant in many parts of the United States. There are not many places left where a person can feel safe in drinking water from a spring, stream or pond. Even the groundwater produced by wells must be tested regularly. In some areas, man's activities have made it difficult to locate a safe water supply of any sort. In certain coastal areas, for example, over-pumping from the ground has depleted the groundwater basins. As a result, the intrusion of sea water is ruining the basin for most useful purposes. Other sources of groundwater contamination include seepage from septic tank leaching systems, agricultural drainage systems, and the improper disposal of hazardous wastes in sanitary landfills and dumps. Some of man's activities clearly pose a serious threat to life on this planet.

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[1] *Acid Rain. Precipitation which has been rendered (made) acidic by airborne pollutants.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 34.

2.0A Why has it become necessary to conserve and properly budget our water resources?

2.0B How are the energy crisis and water shortage linked together?

2.0C Name three ways groundwater may become contaminated.

2.1 SOURCES OF WATER

2.10 The Hydrologic Cycle (Figure 2.1)

All water comes in the form of precipitation. Water evaporates from the ocean by the energy of the sun at an overall rate of about six feet (1.8 m) of water annually. The water which is evaporated is salt-free water, since the heavier mineral salts are left behind. This water vapor rises, is carried along by winds, and eventually condenses into clouds. When these clouds become chilled, the small particles of water collect into larger droplets which may precipitate over land or water. As the water falls in the form of rain, snow, sleet or hail, it clings to and carries with it all the dust and dirt in the air. Needless to say, the first water that falls picks up the greatest concentration of contamination. After a short period of fall, the precipitation is relatively free of pollutants. A large part of the evaporated water is carried over land masses by the winds and the droplets that fall there make up our supply of fresh water. These droplets may soak into the ground, fall as snow on the mountain tops, or collect in lakes, but in one way or another, all of the droplets seek to return to the ocean from where they came. This, in brief, is the framework of the hydrologic cycle.

2.11 Rights to the Use of Water

The rights of an individual to use water for domestic, irrigation or other purposes varies in different states. Some water rights stem from ownership of the land bordering or overlying the source, while others are acquired by a performance of certain acts required by law.

There are three basic types of water rights:

1. *RIPARIAN* — rights which are acquired with title to the land bordering a source of surface water.
2. *APPROPRIATIVE* — rights which are acquired for the beneficial use of water by following a specific legal procedure.
3. *PRESCRIPTIVE* — rights which are acquired by diverting water and putting it to use, for a period of time specified by statute, water to which other parties may or may not have prior claims. The procedure necessary to obtain prescriptive rights must conform with the conditions established by the water-rights laws of individual states.

When there is any question regarding the right to the use of water, a property owner should consult with the appropriate authority and clearly establish rights to its use.

2.12 Ocean

At some time in its history, virtually all water resided in the oceans. By evaporation, moisture is transferred from the ocean surface to the atmosphere, where winds carry the moisture-laden air over land masses. Under certain conditions, this water vapor condenses to form clouds, which release their moisture as precipitation in the form of rain, hail, sleet or snow.

When rain falls toward the earth, part of it may re-evaporate and return immediately to the atmosphere. Precipitation in excess of the amount that wets a surface or evaporates immediately is available as a potential source of water supply.

2.13 Surface Water

2.130 Direct Runoff

Surface water accumulates mainly as a result of direct runoff from precipitation (rain or snow). Precipitation that does not enter the ground through infiltration or is not returned to the atmosphere by evaporation flows over the ground surface and is classified as direct runoff. Direct runoff is water that drains off of saturated or *IMPERMEABLE*[2] surfaces, into stream channels, and then into natural or artificial storage sites (or into the ocean in coastal areas).

The amount of available surface water depends largely upon rainfall. When rainfall is limited, the supply of surface water will vary considerably between wet and dry years. In areas of scant rainfall, people build individual cisterns for the storage of rain which drains from the catchment areas of roofs. This type of water supply is used extensively in areas such as the Bermuda Islands, where groundwater is virtually non-existent and there are no streams.

Surface water supplies may be further divided into river, lake and reservoir supplies. In general, they are characterized by turbidity, suspended solids, some color, and microbiological contamination. Groundwaters, on the other hand, are characterized by higher concentrations of dissolved gases, lower levels of color, and freedom from microbiological contamination.

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[2] *Impermeable. Not able to be penetrated significantly by water.*

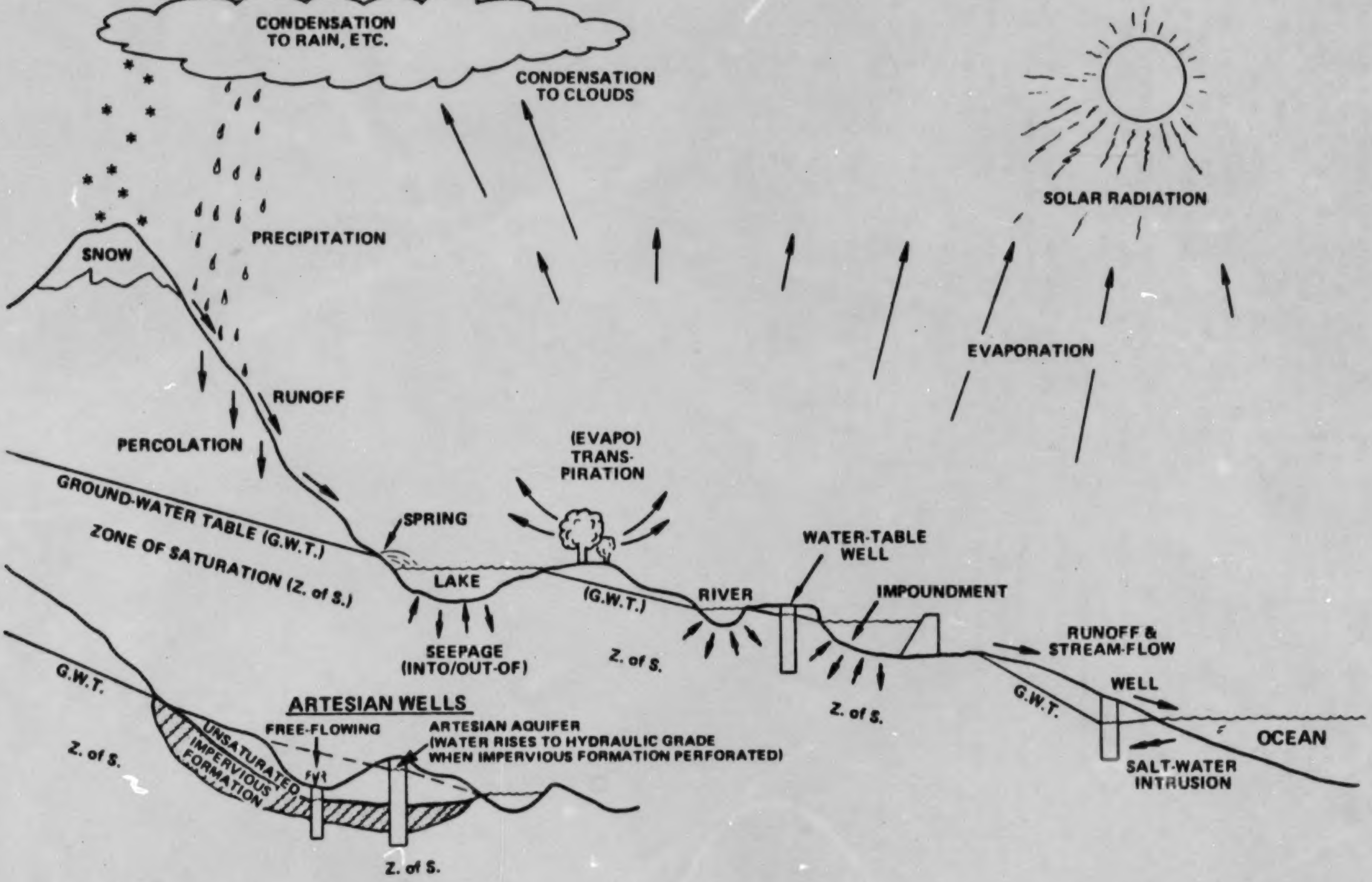
CONDENSATION TO RAIN, ETC.
CONDENSATION TO CLOUDS
SOLAR RADIATION
SNOW
PRECIPITATION
EVAPORATION
RUNOFF
PERCOLATION
(EVAPO) TRANS-PIRATION
GROUND-WATER TABLE (G.W.T.)
ZONE OF SATURATION (Z. of S.)
SPRING
LAKE
SEEPAGE (INTO/OUT-OF)
(G.W.T.)
Z. of S.
RIVER
WATER-TABLE WELL
IMPOUNDMENT
Z. of S.
RUNOFF & STREAM-FLOW
G.W.T.
WELL
OCEAN
SALT-WATER INTRUSION
G.W.T.
Z. of S.
ARTESIAN WELLS
FREE-FLOWING
ARTESIAN AQUIFER (WATER RISES TO HYDRAULIC GRADE WHEN IMPERVIOUS FORMATION PERFORATED)
UNSATURATED IMPERVIOUS FORMATION
Z. of S.

Fig. 2.1 Hydrologic cycle as related to water supply

(Source: *BASIC WATER TREATMENT OPERATOR TRAINING COURSE I*, by Leonard Ainsworth, by permission of California-Nevada Section, AWWA)

2.131 Rivers and Streams

Many of the largest cities in the world depend entirely upon large rivers for their water supplies. In using a river or stream supply, one should always be concerned with upstream conditions. Some cities drink water from a stream or river into which the treated wastewater (sewage) from upstream cities has been discharged. This can present very serious problems in water treatment. Because of upstream pollution (wastewater, agricultural drainage, or industrial waste), the proper treatment of river and stream supplies is extremely important. Rivers and streams are also susceptible to scouring of the bottom, changing channels, and silting. Before the intake for a water supply is located in a river or stream, a careful study must be made of the stream bottom, its degree of scour, and the settling out of silt. Provisions must be made in the design of the intake to make sure that it can withstand the force which will act upon it during times of flood, heavy silting, ice conditions and adverse runoff conditions. Because of variations in the quality of water supplied by a river or stream, purification effectiveness must be continually checked. This is especially true if there are industries upstream from the uptake which may dump undesirable wastes into the supply. Sudden pollutant loads might not be discovered unless constant monitoring of the raw water is maintained by the treatment plant operator.

2.132 Lakes and Reservoirs

The selection and use of water from any surface storage source requires considerable study and thought. When ponds, lakes, or open reservoirs are used as sources of water supply, the danger of contamination and of the consequent spread of diseases such as typhoid, hepatitis, dysentery and giardiasis exists. Clear water is not always safe water and the old saying that running water "purifies itself" to drinking water quality within a stated distance is false.

The potential for contamination of surface water makes it necessary to regard such sources of supply as unsafe for domestic use unless properly treated, including filtration and disinfection. To insure the delivery of a constant, safe drinking water to consumers also requires diligent attention to the operation and maintenance of the distribution system.

Lakes and reservoirs are subject to seasonal changes in water quality such as those brought about by *STRATIFICATION*[3] and the possible increase of organic and mineral contamination that occurs when a lake "turns over." In any body of water, the surface water will be warmed by the sun in spring and summer causing higher temperatures on the surface. Then in the fall, the cooler air temperatures cool the surface water until it reaches the same temperature as the subsurface waters. At this point, the water temperature is fairly uniform (the same) throughout the entire depth of the lake or reservoir. A breeze will start the surface water circulating and cause the lake to "turn over," thus bringing poor quality deeper water to the surface.

Lakes and reservoirs are susceptible to algal blooms, especially after fall or spring turnovers. The rapid growth of algae (blooms) will occur when the temperature is right and the water contains enough nutrients for the rapid growth of algae. In any given body of water, blooms of various types of algae can occur several times during a season depending on what algae is present and whether the conditions are right for algae growth.

Water supplies drawn from large lakes and reservoirs through multiport intake facilities (openings at several depths) are generally of good quality since the water can be drawn from a depth where algal growths are not prevalent. A large lake or reservoir also dilutes any contamination that may have been discharged into it or one of its tributaries.

Large bodies of water are generally attractive recreation areas. If the water is also used for domestic supplies, however, it must be protected from contamination. This will require proper construction and location of recreation facilities such as boat launching ramps, boat harbors, picnic and camping areas, fishing and open beach areas away from the intake area. The location and construction of wastewater collection, treatment and disposal facilities must also be carefully studied to protect domestic water supplies from contamination.

Write your answers in a notebook and then compare your answers with those on page 34.

2.1A What is the hydrologic cycle?

2.1B List the three basic types of water rights.

2.1C What are the general water quality characteristics of surface water supplies?

2.1D What are the general water quality characteristics of groundwater supplies?

2.1E What items should be considered before selecting a location and constructing a water supply intake located in a river or stream?

2.1F What water treatment processes are considered essential to reliably treat physical and bacteriologically contaminated surface waters for domestic use?

2.1G How can provisions be made to allow recreation on water supply lakes and reservoirs without endangering water quality?

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[3] *Stratification (STRAT-uh-fi-KAY-shun). The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature.*

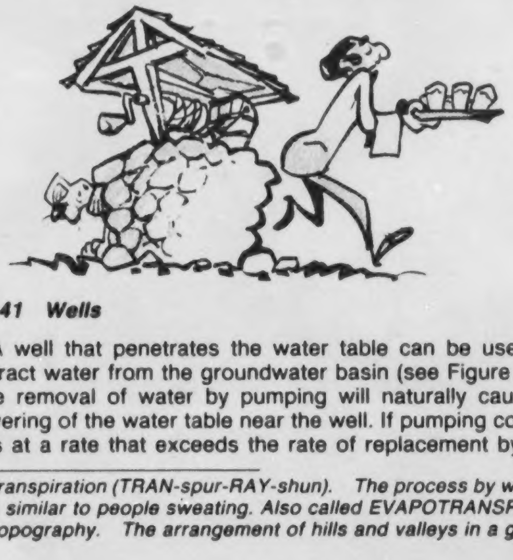
2.14 Groundwater

2.140 Sources (refer to Fig. 2.1, page 25).

Part of the precipitation that falls infiltrates the soil. This water replenishes the soil moisture, or is used by growing plants and returned to the atmosphere by *TRANSPIRATION*[4]. Water that drains downward (percolates) below the root zone finally reaches a level at which all of the openings or voids in the earth's materials are filled with water. This zone is known as the zone of saturation. Water in the zone of saturation is referred to as groundwater. The upper surface of the zone of saturation, if not confined by impermeable material, is called the water table. When an overlying, impermeable formation confines the water in the zone of saturation under pressure, the groundwater is said to be under artesian pressure. The name "artesian" comes from the ancient province of Artesium in France where, in the days of the Romans, water flowed to the surface of the ground from a well. However, not all water from wells that penetrate artesian formations flows to ground level. For a well to be artesian, the water in the well must rise above the top of the aquifer. (An aquifer, or water-bearing formation, is an underground layer of rock or soil which permits the passage of water.)

The porous material just above the water table may contain water by capillarity in the smaller void spaces. This zone is referred to as the capillary fringe. Since the water held in the capillary fringe will not drain freely by gravity, this zone is not considered a true source of supply.

Because of the irregularities in underground deposits or layers and in surface *TOPOGRAPHY*[5], the water table occasionally intersects (meets) the surface of the ground at a spring or in the bed of a stream, lake or the ocean. As a result, groundwater moves to these locations as seepage out of the aquifer (groundwater reservoir). Thus, groundwater is continually moving within aquifers even though the movement may be very slow (see Figure 2.1). The water table (artesian pressure surface) thus may slope from areas of recharge to lower areas of discharge. The pressure difference represented by these slopes causes the flow of groundwater within the aquifer. Seasonal variations in the supply of water to the underground reservoir cause considerable changes in the elevation and slope of the water table and the artesian pressure level.



2.141 Wells

A well that penetrates the water table can be used to extract water from the groundwater basin (see Figure 2.1). The removal of water by pumping will naturally cause a lowering of the water table near the well. If pumping continues at a rate that exceeds the rate of replacement by the water-bearing formations, the "sustained yield" of the well or group of wells has been exceeded. The "safe yield" will be exceeded if wells extract water from an aquifer over a period of time at a rate that will deplete the aquifer and bring about other undesired results (such as sea water intrusion and land subsidence). This situation is a poor practice, but occurs quite frequently in many areas of the U.S.

2.142 Springs

Groundwater that flows naturally from the ground is called a spring. Depending upon whether the discharge is from a water table or an artesian aquifer, springs may flow by gravity or by artesian pressure. The flow from a spring may vary considerably; when the water table or artesian pressure fluctuates, so does the flow from the spring.

2.15 Reclaimed Water

The use of treated wastewater as a source of water for non-food crop irrigation is an established practice in many regions of the world. The type of crop which can be safely irrigated depends somewhat on the quality of wastewater and method of irrigation. At the present time, more than 20,000 acres (8,000 hectares) of agricultural lands in California are irrigated, all or in part, with reclaimed water. Two of the largest operations are at Bakersfield and at Fresno, California. The City of Bakersfield has used wastewater effluent for irrigation since 1912. At the present time, approximately 2,400 acres (1,000 hectares) of alfalfa, cotton, barley, sugar beets and pasture are irrigated. Fresno irrigates 3,500 acres (1,400 hectares) of the same type of crops. These two operations use almost 30,000 acre-feet (37 million cubic meters) of reclaimed water per year. Almost 90 percent of the 2,000,000 acre-feet (2.5 billion cubic meters) of reclaimed wastewater in California is used for crop irrigation.

Other uses for reclaimed wastewater include:

1. Greenbelt (parks) areas,
2. Golf course irrigation,
3. Landscape irrigation,
4. Industrial reuse,
5. Groundwater recharge,
6. Landscape impoundments, and
7. Wetlands — marsh enhancement.

Reclaimed water can be used safely for any of these purposes, with the possible exception of groundwater recharge. Health experts have serious questions regarding organic compounds that are present in wastewater and about our ability to reduce them to safe levels. These doubts increase further when we realize that a large number of new and potentially toxic chemicals are developed each year. Laboratories are unable to adequately detect all of these chemicals without expensive monitoring programs. To protect groundwater resources regulations require that "reclaimed water used for groundwater recharge of domestic water supply aquifers by surface spreading shall be at all times of a quality that fully protects public health." Proposed groundwater recharge projects must be investigated on an individual basis where the use of reclaimed water involves a potential risk to public health.

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[4] *Transpiration (TRAN-spur-RAY-shun). The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.*

[5] *Topography. The arrangement of hills and valleys in a geographic area.*

Treatment of reclaimed water should be appropriate for the intended use. The greater the potential exposure to the public, the more extensive the treatment needs to be. Regulations often specify not only the degree of treatment for the useage of water, but also the reliability features that must be incorporated into the treatment processes to assure a continuous high degree of finished water quality. Studies indicate that the average reclamation plant does not achieve the quality of treatment expected on a continuous basis. This is of concern to the water supplier and also the regulatory agencies that are charged with the responsibility of assuring that the health of the public is protected.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 34.

2.1H What causes the flow of groundwater within an aquifer?

2.1I How can the "safe yield" of an aquifer be exceeded?

2.1J List some of the possible uses of reclaimed wastewater.

2.1K How much treatment should reclaimed water receive before use?

2.2 SELECTION OF A WATER SOURCE

2.20 Sanitary Survey[6]

The importance of detailed sanitary surveys of water supply sources cannot be overemphasized. With a new supply, the sanitary survey should be made during the collection of initial engineering data covering the development of a given source and its capacity to meet existing and future needs. The sanitary survey should include the location of all potential and existing health hazards and the determination of their present and future importance. Persons trained in public health engineering and the *EPIDEMIOLOGY*[7] of water-borne diseases should conduct the sanitary survey. In the case of an existing supply, sanitary surveys should be made frequently enough to control health hazards and to maintain high water quality.

The information furnished by a sanitary survey is essential to evaluating the bacteriological and chemical water quality data. The following outline lists the essential factors which should be investigated or considered in a sanitary survey. These items are essential to (1) identify potential hazards, (2) determine factors which affect water quality, and (3) select treatment requirements. Not all of the items are important to any one supply and, in some cases, items not in the list could be found to be significant during the field investigation.

GROUNDWATER SUPPLIES:

a. Character of local geology; slope (topography) of ground surface.

b. Nature of soil and underlying porous material; whether clay, sand, gravel, rock (especially porous limestone); coarseness of sand or gravel; thickness of water-bearing stratum; depth of water table; location and *GEOLOGICAL LOG*[8] of nearby wells.

c. Slope of water table, preferably as determined from observation wells or as indicated by slope of the ground surface.

d. Extent of the drainage area likely to contribute water to the supply.

e. Nature, distance, and direction of local sources of pollution.

f. Possibility of surface-drainage water entering the supply and of wells becoming flooded.

g. Methods used for protecting the supply against contamination from wastewater collection and treatment facilities and industrial waste disposal sites.

h. Well construction: materials, diameter, depth of casing and concrete collar; depth to well screens or perforations; length of well screens or perforations.

i. Protection of well head at the top and on the sides.

j. Pumping station construction (floors, drains); capacity of pumps; storage or direct to distribution system.

k. Drawdown when pumps are in operation; recovery rate when pumps are off.

l. Presence of an unsafe supply nearby, and the possibility of *CROSS-CONNECTIONS*[9] causing a danger to the public health.

m. Disinfection: equipment, supervision, test kits, or other types of laboratory control.

SURFACE WATER SUPPLIES:

a. Nature of surface geology; character of soils and rocks.

b. Character of vegetation; forests; cultivated and irrigated land.

c. Population and wastewater collection, treatment and disposal on the watershed.

d. Methods of wastewater disposal, whether by diversion from watershed or by reclamation treatment.

e. Closeness of sources of fecal pollution (especially birds) to intake of water supply.

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[6] *Sanitary Survey. A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, and treatment and distribution facilities to insure its protection from all pollution sources.*

[7] *Epidemiology (EP-uh-DEE-me-ALL-O-gee). A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.*

[8] *Geological Log. A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).*

[9] *Cross-Connection. A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.*

f. Proximity and character of sources of industrial wastes, oil field brines, acid waters from mines, and agricultural drain waters.

g. Adequacy of supply as to quantity (safe yield).

h For lake or reservoir supplies: wind direction and velocity data; drift of pollution; and algae growth potential.

i. Character and quality of raw water: typical coliform counts (MPN or membrane filter), algae, turbidity, color, and objectionable mineral constituents.

j. Normal period of *DETENTION TIME*[10].

k. Probable minimum time required for water to flow from sources of pollution to reservoir and through the reservoir to the intake tower.

l. The possible currents of water within the reservoir (induced by wind or reservoir discharge) which could cause *SHORT-CIRCUITING*[11] to occur.

m. Protective measures in connection with the use of the watershed to control fishing, boating, landing of airplanes, swimming, wading, ice cutting, and permitting animals on shore-line areas.

n. Efficiency and constancy of policing activities on the watershed and around the lake.

o. Treatment of water: kind and adequacy of equipment; duplication of parts for reliable treatment; effectiveness of treatment; numbers and competency of supervising and operating personnel; contact period after disinfection; free chlorine residuals and monitoring of the water supply both during treatment and following treatment.

p. Pumping facilities: pump station design, pump capacity and standby unit(s).

q. Presence of an unsafe supply nearby, and the possibility of cross-connections causing a danger to the public health.

2.21 Precipitation

Precipitation in the form of rain, snow, hail, or sleet contains very few impurities. (However, there are exceptions such as acid rain and dust from Dust Bowl areas.) Trace amounts of mineral matter, gases, and other substances may be picked up by precipitation as it forms and falls through the earth's atmosphere. Precipitation, however, has virtually no microbiological content.

Once precipitation reaches the earth's surface, many opportunities are presented for the introduction of mineral and organic substances, microorganisms, and other forms of contamination. When water runs over or through the ground surface it may pick up particles of soil. This is noticeable in the water as cloudiness or turbidity. This water also picks up particles or organic matter and microorganisms. As surface water seeps downward into the soil and through the underlying material to the water table, most of the suspended particles are filtered out. This natural filtration may be partially effective in removing microorganisms and other particulate materials; however, the chemical characteristics of the water usually change considerably when it comes in contact with underground mineral deposits.

The widespread use of synthetically-produced chemical compounds, especially pesticides, has raised concern for their potential to contaminate water. Many of these materials are known to be toxic (poisonous), some cause cancer, and others have certain undesirable characteristics even when present in a relatively small concentration.

Agents which alter the quality of water as it moves over or below the surface of the earth may be classified under four major headings:

A. *PHYSICAL* — Physical characteristics relate to the sensory qualities of water for domestic use; for example, the water's observed color, turbidity, temperature, taste and odor.

B. *CHEMICAL* — Chemical differences between waters include mineral content and the presence or absence of constituents such as fluoride, sulfide, and acids. The comparative performance of hard and soft waters in laundering is one visible effect.

C. *BIOLOGICAL* — The presence of organisms (virus, bacteria, algae, mosquito larvae), alive or dead, and their metabolic products determine the biological character of water. These may also be significant in modifying the physical and chemical characteristics of water.

D. *RADIOLOGICAL* — Radiological factors must be considered because there is a possibility that the water may have come in contact with radioactive substances.

Consequently, in the development of water supply systems, it is necessary to examine carefully all the factors which might adversely affect the water supply.

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[10] *Detention Time. In storage reservoirs, detention time is the length of time entering water is held before being drafted for use (several weeks to years, several months being typical).*

[11] *Short-Circuiting. A usually undesirable condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This results in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 34 and 35.

2.2A What is the purpose of a sanitary survey?

2.2B How frequently should a sanitary survey be conducted for an existing water supply?

2.2C When conducting a sanitary survey, what protective measures should be investigated regarding use of the watershed?

2.2D List the common physical characteristics of water.

2.22 Physical Characteristics

To be suitable for human use, water should be free from all impurities which are offensive to the senses of sight, taste, and smell. The physical characteristics which might be offensive include turbidity, color, taste, odor and temperature.

TURBIDITY: The presence of suspended material in water causes cloudiness which is known as turbidity. Clay, silt, finely divided organic material, plankton, and other inorganic materials give water this appearance. Turbidities in excess of 5 turbidity units are easily visible in a glass of water, and this level is usually objectionable for aesthetic reasons. Turbidity's major danger in drinking water is that it can harbor bacteria as well as exert a high demand on chlorine. Water that has been filtered to remove the turbidity should have considerably less than one turbidity unit. Good treatment plants consistently obtain finished water turbidity levels of from 0.05 to 0.3 units.

COLOR: Dissolved organic material from decaying vegetation and certain inorganic matter cause color in water. Occasionally, excessive blooms of algae or the growth of other aquatic microorganisms may also impart color. Iron and manganese may be the cause of consumer complaints (red or black water). While the color itself is not objectionable from the standpoint of health, its presence is aesthetically objectionable and suggests that the water needs better treatment. In some instances however, a color in the water indicates more than an aesthetic problem. For example, an amber color in the water could indicate the presence of humic substances which could later be formed into trihalomethanes or it could indicate acid waters from mine drainage.

TEMPERATURE: The most desirable drinking waters are consistently cool and do not have temperature fluctuations of more than a few degrees. Groundwater and surface water from mountainous areas generally meet these requirements. Most individuals find that water having a temperature between 50° and 60°F (10° and 15°C) is most pleasing while water over 86°F (30°C) is not acceptable. The temperature of groundwaters varies with the depth of the aquifer. Water from very deep wells (more than 1000 ft or 300 m) may be quite warm. Temperature also affects sensory perception of tastes and odors.

TASTES: Each area's natural waters have a distinctive taste related to the dissolved mineral characteristics of local geology. Occasionally, algal growths also impact a distinctive taste. However, taste is rarely measured since most water treatment plants cannot alter a water's mineral characteristics.

ODORS: Growths of algae in a water supply can give the water an unpleasant odor. Some groundwaters may contain hydrogen sulfide which will produce a disagreeable rotten egg odor.

2.23 Chemical Characteristics

The nature of the materials that form the earth's crust affects not only the quantity of water that may be recovered, but also its chemical makeup. As surface water infiltrates and percolates downward to the water table, it dissolves some of the minerals contained in soils and rocks. Groundwater, therefore, sometimes contains more dissolved minerals than surface water. The use and disposal of chemicals by society can also [illegible]ect water quality.

Chemical analys[illegible] of a domestic water supply, is broken down into three areas:

1. Inorganic chemicals; which include the toxic (poisonous) metals — arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver; and the nonmetals — fluoride and nitrate.
2. Organic chemicals which include the pesticides (chlorinated hydrocarbons) — Endrin, Lindane, Methoxychlor and Toxaphene, and the Chlorophenoxys; and
3. The general mineral constituents which include alkalinity, calcium, chloride, copper, foaming agents (MBAS), iron, magnesium, manganese, pH, sodium, sulfate, zinc, specific conductance, total dissolved solids, and hardness (calcium and magnesium).

Upper limits for the concentrations of the chemicals listed in this section have been established by the Safe Drinking Water Act. For a summary of the Drinking Water Regulations established by the Act, see the poster included with this manual. Chapter 22, "Drinking Water Regulations," *WATER TREATMENT PLANT OPERATION*, Volume II, contains a detailed discussion of the Safe Drinking Water Act.

2.24 Biological Factors

Water for domestic purposes must be made free from disease-producing (pathogenic) organisms. These organisms include bacteria, protozoa, spores, viruses, cysts, and helminths (parasitic worms).

Many organisms which cause disease in man originate with the fecal discharges of infected individuals. To monitor and control the activities of human disease-carriers is seldom practical. For this reason, it is necessary to take precautions to prevent contamination of a normally safe water source or to institute treatment methods which will produce a safe water.

Unfortunately, the specific disease-producing organisms present in water are not easily isolated and identified. The techniques for comprehensive bacteriological examination are complex and time-consuming. Therefore, it has been necessary to develop tests which indicate the relative degree of contamination in terms of an easily defined quality. The most widely used test involves estimation of the number of bacteria of the coliform group, which are always present in fecal wastes and vastly outnumber disease-producing organisms. Coliform bacteria normally inhabit the intestinal tract of man, but are also found in most animals and birds, as well as in the soil. The Drinking Water Standards in the Safe Drinking Water Act have established upper limits for the concentration of coliform bacteria in a series of water samples (roughly, no more than one organism per 100 mL of sample water).

2.25 Radiological Factors

The development and use of atomic energy as a power source and the mining of radioactive materials have made it necessary to examine the safe limits of exposure for humans. Such limits include concentrations of radioactive material taken into the body in drinking water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 35.

2.2E What causes turbidity in water?

2.2F Chemical analysis of a domestic water supply measures what three general types of chemical concentrations?

2.2G Why are coliform bacteria used to measure the bacteriological quality of water?

2.2H Why must upper limit concentrations of radioactive materials in drinking water be established?

2.3 THE SAFE DRINKING WATER ACT

On December 16, 1974, the Safe Drinking Water Act (SDWA) was signed into law. The Act set up a cooperative program among local, state and federal agencies. As directed by the Act the Environmental Protection Agency developed primary drinking water regulations designed to insure safe drinking water for consumers.

A study of the health effects of various contaminants in water was begun soon after the SDWA was signed into law. The regulations were developed in two stages so that the findings of this investigation and other studies could be incorporated into the regulations. The interim regulations became effective June 24, 1977, and they were followed by revised regulations.

All public water systems must comply with the regulations. This includes all public or privately owned systems that:

1. Have at least 15 service connections which are used at least 60 days out of the year, or
2. Serve an average of at least 25 people at least 60 days out of the year.

The regulations apply to two kinds of public water systems: (1) community water systems, and (2) non-community water systems.

A community water system is defined as follows:

1. Has at least 15 service connections used by all-year residents, or
2. Services at least 25 all-year residents.

A non-community water system is defined as follows:

1. Has at least 15 service connections used by travelers or intermittent users at least 60 days a year, or
2. Services a daily average of at least 25 people at least 60 days a year.

Water has many important uses and each requires certain specific levels of water quality. The major concern of the operators of water treatment plants and water supply systems is to produce and deliver to consumers water meeting the standards established by the Safe Drinking Water Act. The water should be acceptable to domestic and commercial water users and many industries. Some industries, such as food and drug processors and the electronics industry, require higher quality water. Many industries will locate where the local water supply meets their specific needs while other industries may have their own water treatment facilities to produce water suitable for their needs.

SA
RINKING WA
ACT

The maximum contaminant levels (MCLs) and also the sampling and testing requirements established by the Safe Drinking Water Act are summarized on the poster included with this manual. For additional information on the Safe Drinking Water Act, see *WATER TREATMENT PLANT OPERATION*, Volume II, Chapter 22, "Drinking Water Regulations."

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 35.

2.3A The Safe Drinking Water Act (SDWA) set up a cooperative program among which agencies?

2.3B What were the two stages under which the regulations under the SDWA were developed?

2.3C Community and non-community water systems are different in what respect?

2.3D Which industries require extremely high quality water?

2.4 WATER TREATMENT

In the operation of water treatment plants, three basic objectives are controlling:

1. Production of a safe drinking water,
2. Production of an aesthetically pleasing drinking water, and
3. Production of drinking water at a reasonable cost with respect to capital and also operation and maintenance costs.

From a public health perspective, production of a safe drinking water, one that is free of harmful bacteria and toxic materials, is the first priority. But, it is also important to produce a high quality water which appeals to the consumer. Generally, this means that the water must be clear (free of turbidity), colorless, and free of objectionable tastes and odors. Consumers also show a preference for water supplies that are nonstaining (plumbing fixtures and washing clothes), noncorrosive to plumbing fixtures and piping, and one that does not leave scale deposits or spot glassware.

Consumer sensitivity to the environment (air quality, water quality, noise) has significantly increased in recent years. With regard to water quality, consumer demands have never been greater. In some instances, consumers have substituted bottled water to meet specific needs, namely, for drinking water and cooking purposes.

Design engineers select water treatment processes on the basis of the type of water source, source water quality, and desired finished water quality established by drinking water regulations and consumer desires. Table 2.1 is a summary of typical water treatment processes and plants depending on the source and quality of the raw water.

Operators of water treatment facilities must be very conscientious in order to produce a high quality finished water. Also they must realize that water can degrade in the distribution or delivery system. The remainder of this manual contains chapters written by operators on how to produce and deliver high quality drinking water to consumers.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 35.

2.4A What is the first priority for operating a water treatment plant?

2.4B What type of water is appealing to consumers?

TABLE 2.1 SOURCES AND TREATMENT OF WATER

GROUNDWATER

WATER QUALITY PROBLEM	*TREATMENT*[a]
1. Coliforms or Microbiological Contamination	1. Disinfection (Chlorination)
2. Sulfide Odors (Rotten Egg)	2a. Aeration 2b. Oxidation (Chlorination) 2c. Desulfuration (Sulfur Dioxide)
3. Excessive Hardness (Calcium and Magnesium)	3a. Ion Exchange Softening 3b. Lime (& Soda) Softening
4. Iron and/or Manganese	4a. Sequestration (Polyphosphates) 4b. Removal by Special Ion Exchange 4c. Permanganate and Greensand 4d. Oxidation by Aeration* 4e. Oxidation with Chlorine* 4f. Oxidation with Permanganate* *Filtration Must Follow Oxidation
5. Dissolved Minerals (High Total Dissolved Solids)	5a. Ion Exchange 5b. Reverse Osmosis
6. Corrosivity (Low pH)	6a. pH Adjustment with Chemicals 6b. Carbon Dioxide Stripping by Aeration 6c. Corrosion Inhibitor Addition (Zinc Phosphate, Silicate)
7. Preventive Treatment (Fluoridation)	7. Add Fluoride Chemicals
8. Sand	8. Sand Separators
9. Nitrate	9. Anion Exchange

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[a] For details on the treatment processes, refer to the appropriate chapters in these manuals.

TABLE 2.1 SOURCES AND TREATMENT OF WATER (Continued)

SURFACE WATER

WATER QUALITY PROBLEM	*TREATMENT*[a]
1. Coliforms or Microbiological Contamination	1a. Disinfection (Chlorination) 1b. Disinfection (Other Oxidants — Ozone, Chlorine Dioxide, Chloramination) 1c. Coagulation, Flocculation, Sedimentation, Filtration and Disinfection
2. Turbidity, Color	2. Coagulation, Flocculation, Sedimentation and Filtration
3. Odors (Organic Materials)	3a. Clarification (Coagulation, Flocculation, Sedimentation and Filtration) 3b. Oxidation (Chlorination or Permanganate) 3c. Special Oxidation (Chlorine Dioxide) 3d. Adsorption (Granular Activated Carbon)
4. Iron and/or Manganese	4a. Sequestration (Polyphosphates) 4b. Removal by Special Ion Exchange 4c. Permanganate and Greensand 4d. Oxidation by Aeration* 4e. Oxidation with Chlorine* 4f. Oxidation with Permanganate* *Filtration Must Follow Oxidation
5. Excessive Hardness (Calcium and Magnesium)	5a. Ion Exchange Softening 5b. Lime (& Soda) Softening
6. Dissolved Minerals (High Total Dissolved Solids)	6a. Ion Exchange 6b. Reverse Osmosis
7. Corrosivity (Low pH)	7a. pH Adjustment with Chemicals 7b. Corrosion Inhibitor Addition (Zinc Phosphate, Silicate)
8. Preventive Treatment	
a. Fluoridation	8a. Add Fluoride Chemicals
b. Trihalomethanes (THMs)	8b. (1) Do not Prechlorinate. Disinfect with Ozone, Chlorine Dioxide, or Chloramination (2) Remove THM Precursors (3) Remove THMs after They Are Formed

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[a] For details on the treatment processes, refer to the appropriate chapters in these manuals.

2.5 ARITHMETIC ASSIGNMENT

A good way to learn how to solve arithmetic problems is to work on them a little bit at a time. In this operator training manual we are going to make a short arithmetic assignment at the end of every chapter. If you will work this assignment at the end of every chapter, you can easily learn how to solve waterworks arithmetic problems.

Turn to the Appendix at the back of this manual and read the following sections:

1. OBJECTIVES,
2. A.O HOW TO STUDY THIS APPENDIX, and
3. A.1 BASIC ARITHMETIC.

Solve all of the problems in Sections A.10, Addition; A.11, Subtraction; A.12, Multiplication; A.13, Division; A.14, Multiplication and Division; and A.15, Actual Problems; on an electronic pocket calculator.

2.6 ADDITIONAL READING

1. AWWA. *INTRODUCTION TO WATER SOURCES AND TRANSMISSION,* Volume I, Module 1, "Sources and Characteristics."
2. *NEW YORK MANUAL,* Chapter 2, "Water Sources and Water Uses."
3. *TEXAS MANUAL,* Chapter 2, "Groundwater Supplies;" Chapter 3, "Surface Water Supplies;" and Chapter 4, "Raw Water Quality Management."
4. *WATER: A PRIMER,* by Luna B. Leopold. Available from W.H. Freeman and Company, San Francisco, CA 94104. Price, $20.25

DISCUSSION AND REVIEW QUESTIONS

Chapter 2. WATER SOURCES AND TREATMENT

DO NOT USE IBM ANSWER SHEET. Please write your answers to these questions in your notebook before continuing with the Objective Test on page 35. The purpose of these questions is to indicate to you how well you understand the material in this chapter.

1. What has been the impact of drought conditions on the managers of water supplies?
2. Why has the quality of many water supplies deteriorated?
3. How does the hydrologic cycle work?
4. What are water rights?
5. What are the differences between the water quality characteristics of groundwater and surface water supplies?
6. Lakes turn over under what conditions?
7. Algae blooms in reservoirs occur under what general conditions?
8. How can a lake used for a water supply also be used for recreation without endangering water quality?
9. The elevation and slope of water tables and artesian pressure levels can change due to what factors?
10. Who should conduct a sanitary survey? Why?

SUGGESTED ANSWERS

Chapter 2. WATER SOURCES AND TREATMENT

Answers to questions on page 24.

2.0A Drought conditions have forced water supply managers to recognize the need to conserve and properly budget our water resources. Other reasons include the increasing costs of energy and chemicals.

2.0B The energy crisis and water shortage are linked together because (1) with falling groundwater levels energy is required to pump from deeper levels, and (2) water projects that use large amounts of electricity to pump water over long distances are requiring water users to pay increased water rates to cover higher energy costs.

2.0C Groundwater becomes contaminated from (1) sea water intrusion, (2) seepage from septic tank leaching systems, (3) agricultural drainage systems, and (4) seepage from improper disposal of hazardous wastes.

Answers to questions on page 26.

2.1A The hydrologic cycle is the cycle or path water follows from evaporation from oceans, to formation of clouds, to precipitation, to runoff, to evaporation and transpiration back to the atmosphere, and eventually back to the ocean.

2.1B The three basic types of water rights are:
1. Riparian,
2. Appropriative, and
3. Prescriptive.

2.1C In general, surface water supplies are characterized by suspended solids, turbidity, some color, and microbiological contamination.

2.1D In general, groundwater supplies are characterized by higher concentrations of dissolved gases, and low color, but freedom from bacterial contamination.

2.1E Before selecting a location and constructing a water supply intake in a river or stream, careful consideration must be given to (1) the stream bottom, its degree of scour, and the settling out of silt, and (2) design of the intake to make sure that it can withstand the forces which will act upon it during times of flood, heavy silting, ice conditions, and adverse runoff conditions.

2.1F Filtration and disinfection are considered essential water treatment processes to reliably treat physically and bacteriologically contaminated surface waters for domestic use.

2.1G Lakes and reservoirs used for domestic water supplies can be protected from contamination by (1) proper construction and location of recreation facilities; and (2) careful evaluation of adverse effects of the construction of wastewater collection, treatment and disposal facilities near the reservoir or its tributaries.

Answers to questions on page 28.

2.1H Groundwater flows within an aquifer because of the pressure differences between the areas of recharge and discharge.

2.1I The "safe yield" of an aquifer can be exceeded if wells extract water from an aquifer over a period of time at a rate such that the aquifer will become depleted or bring about other undesired results, such as sea water intrusion and land subsidence.

2.1J Possible uses of reclaimed wastewater include: (1) crop irrigation, (2) greenbelt irrigation, (3) golf course irrigation, (4) landscape irrigation, (5) industrial reuse, (6) groundwater recharge, (7) landscape impoundments, and (8) wetlands — marsh enhancement.

2.1K Reclaimed water should receive treatment that is appropriate for the intended use of the water.

Answers to questions on page 30.

2.2A The purpose of a sanitary survey is to detect all health hazards and to evalute their present and future importance.

2.2B For an existing water supply, a sanitary survey should be made frequently enough to control all health hazards and to maintain good sanitary water quality.

2.2C When conducting a sanitary survey, protective measures that should be investigated include control of sources of waste discharges (municipal wastewater treatment plants, sources of fecal pollution, industrial wastes, oil field brines, acid waters from mines, and agricultural drain waters), fishing, boating, landing of airplanes, swimming, wading, ice cutting, and permitting animals on shore-line areas.

2.2D The common physical characteristics of water are observable color, turbidity, temperature, taste, and odor.

Answers to questions on page 31.

2.2E Turbidity in water is caused by the presence of suspended material such as clay, silt, finely divided organic material, plankton, and other inorganic material.

2.2F The three general types of chemicals measured by a chemical analysis of domestic water supplies are inorganic, organic and general mineral concentrations.

2.2G Coliforms are used to measure the bacteriological quality of drinking water because the test indicates the fecal contamination where specific disease-producing organisms are not easily isolated and identified.

2.2H The development and use of atomic energy as a power source and the mining of radioactive materials have made it necessary to establish upper limit concentrations for drinking water.

Answers to questions on page 32.

2.3A The Safe Drinking Water Act (SWDA) set up a cooperative program among local, state and federal agencies.

2.3B The regulations under the SDWA were developed in two stages so that findings of investigations and other studies could be incorporated into the regulations. The interim regulations became effective June 24, 1977, and they were followed by revised regulations.

2.3C Community water systems serve all-year residents while non-community systems serve consumers at least 60 days a year.

2.3D Food and drug processors and also electronic industries require extremely high quality water.

Answers to questions on page 32.

2.4A The first priority for operating a water treatment plant is the production of a safe drinking water, one that is free of harmful bacteria and toxic materials.

2.4B Water that appeals to consumers must be clear (free of turbidity), colorless, and free of objectionable tastes and odors. Consumers also show a preference for water supplies that are nonstaining (plumbing fixtures and washing clothes), noncorrosive to plumbing fixtures and piping, and one that does not leave scale deposits or spot glassware.

OBJECTIVE TEST

Chapter 2. WATER SOURCES AND TREATMENT

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

True-False

1. The energy crisis and water shortages are linked together.
   1. True
   2. False

2. Both animal life and plant life depend on water for survival.
   1. True
   2. False

3. Large cities may obtain their raw water supply from a stream or river into which the treated wastewater from an upstream city has been discharged.
   1. True
   2. False

4. Laboratories can easily detect in water samples most of the new chemicals that are developed each year.
   1. True
   2. False

5. Acid rain is formed by the evaporation of acid waters from mine drainage.
   1. True
   2. False

6. Precipitation is high in bacterial count.
   1. True
   2. False

7. Color in water is objectionable from the standpoint of health.
   1. True
   2. False

8. The specific disease-producing organisms present in water are easily identified.
   1. True
   2. False

9. Clear water is usually safe to drink.
   1. True
   2. False

10. Running water usually purifies itself to drinking water quality within a reasonable distance.
    1. True
    2. False

Multiple Choice

11. Sources of contamination of water supplies include
    1. Acid rain.
    2. Industrial waste discharges.
    3. Intrusion of sea water into groundwater basins.
    4. Mineral residues from irrigation.
    5. Salt from de-icing highways.

12. Sources of groundwater contamination include
    1. Agricultural drainage.
    2. Sea water intrusion.
    3. Seepage from septic tank leaching systems.
    4. Seepage from improper disposal of hazardous wastes.
    5. Surface runoff.

13. The basic types of water rights are called
    1. Acquired.
    2. Appropriative.
    3. Beneficial.
    4. Prescriptive.
    5. Riparian.

14. For purposes of discussion, surface water supplies may be divided into which of the following classes?
    1. Artesian aquifers
    2. Lakes
    3. Reservoirs
    4. Rivers
    5. Wells

15. Diseases that may be spread through a water supply include
    1. Chicken pox.
    2. Dysentery.
    3. Giardiasis.
    4. Small pox.
    5. Typhoid fever.

16. Typical uses of reclaimed water include
    1. Crop irrigation.
    2. Drinking.
    3. Industrial reuse.
    4. Landscape impoundments.
    5. Landscape irrigation.

17. When conducting a sanitary survey, which of the following items would pertain to a groundwater supply?
    1. Distance to sources of pollution
    2. Nature of soil
    3. Slope of ground surface
    4. Slope of water table
    5. Well construction

18. When conducting a sanitary survey, which of the following items would pertain to a water supply in a lake?
    1. Adequacy of supply as to quantity
    2. Algae growth potential
    3. Normal period of detention
    4. Protective measures in connection with watershed use
    5. Wind direction

19. Items requiring protective measures in watersheds that serve as the source of a water supply include control of
    1. Disposal of brines.
    2. Fishing.
    3. Ice cutting.
    4. Sanitary landfills.
    5. Swimming.

20. Which types of substances may alter the quality of water as it moves over or below the surface of the earth?
    1. Biological
    2. Chemical
    3. Epidemiological
    4. Physical
    5. Radiological

21. Turbidity in water results from the presence of
    1. Finely divided organic material.
    2. Hardness.
    3. pH.
    4. Plankton.
    5. Suspended material.

22. Most individuals find that water having a temperature between ________ is most palatable.
    1. 30 to 40°F
    2. 40 to 50°F
    3. 50 to 60°F
    4. 60 to 70°F
    5. 70 to 80°F

23. The process by which water vapor is released to the atmosphere by living plants is called
    1. Evaporation.
    2. Hydrologic cycle.
    3. Infiltration.
    4. Precipitation.
    5. Transpiration.

24. Water quality characteristics of surface water supplies include
    1. Absence of color.
    2. Freedom from microbiological contamination.
    3. High concentrations of dissolved gases.
    4. Suspended solids.
    5. Turbidity.

25. Lakes and reservoirs are susceptible to algal blooms when
    1. Maximum cloud cover occurs.
    2. Optimum level of hardness is present.
    3. Sufficient nutrients are available.
    4. Temperature is right.
    5. Water is completely stratified.

26. Sources of odors in drinking water include
    1. Dissolved oxygen.
    2. Growths of algae.
    3. Hydrogen sulfide.
    4. pH.
    5. Temperature.

27. A public water system according to the Safe Drinking Water Act (SWDA) includes all public or privately owned systems that
    1. Are owned and operated by a public agency.
    2. Have at least 15 service connections which are used at least 60 days out of the year.
    3. Have at least 25 service connections which are used at least 60 days out of the year.
    4. Serve an average of at least 15 people at least 60 days out of the year.
    5. Serve an average of at least 25 people at least 60 days out of the year.

28. The basic objectives in the operation of a water treatment plant include
    1. Keeping management happy.
    2. Keeping regulatory agencies happy.
    3. Production of a safe drinking water.
    4. Production of an aesthetically pleasing drinking water.
    5. Production of drinking water at a reasonable cost.

29. Determine the chlorinator setting in pounds per day if

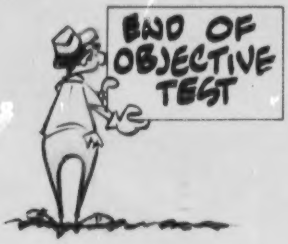
$$\text{Chlorinator Feed Rate, lbs/day} = (2\ \text{MGD})(3\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

    1. 6 lbs/day
    2. 16 lbs/day
    3. 24 lbs/day
    4. 36 lbs/day
    5. 50 lbs/day

30. Estimate the chlorine dose to a drinking water in mg/*L* if

$$\text{Chlorine Dose, mg}/L = \frac{14\ \text{lbs/day}}{(0.933\ \text{MGD})(8.34\ \text{lbs/gal})}$$

    1. 0.3 mg/*L*
    2. 1.8 mg/*L*
    3. 2.5 mg/*L*
    4. 3.3 mg/*L*
    5. 7.8 mg/*L*



CHAPTER 3

RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

by

Richard H. Barnett

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OBJECTIVES

Chapter 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

Following completion of Chapter 3, you should be able to:

1. Describe the importance of reservoir management;
2. Identify causes of reservoir water quality problems;
3. Justify the need for a reservoir management program;
4. Implement the appropriate methods of reservoir management and water quality improvement;
5. Develop a laboratory and monitoring program;
6. Describe the purpose of intake structures;
7. Identify various types of intake structures, gates, and screens;
8. Safely operate, maintain and troubleshoot intake facilities; and
9. Keep necessary records on the operation and maintenance of reservoir water quality management programs and intake structures.

GLOSSARY

Chapter 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

ACRE-FOOT ACRE-FOOT

A volume of water that covers one acre a depth of one foot, or 43,560 cubic feet (1233.5 cubic meters).

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AERATION (air-A-shun) AERATION

The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

AEROBIC (air-O-bick) AEROBIC

A condition in which "free" or dissolved oxygen is present in the water.

ALGAE (AL-gee) ALGAE

Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.

ALGAL BLOOM (AL-gal) ALGAL BLOOM

Sudden, massive growths of microscopic and macroscopic plant life, such as green or blue-green algae, which develop in lakes and reservoirs.

ALIPHATIC HYDROXY ACIDS (AL-uh-FAT-ick) ALIPHATIC HYDROXY ACIDS

Organic acids with carbon atoms arranged in branched or unbranched open chains rather than in rings.

ANAEROBIC (AN-air-O-bick) ANAEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is *NOT* present in the water.

ANION (AN-EYE-en) ANION

A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of a difference in electrical potential. Chloride (Cl^-) is an anion.

BIOCHEMICAL OXYGEN DEMAND BIOCHEMICAL OXYGEN DEMAND

BOD. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

A system for prevention of rust, corrosion, and pitting of metal surfaces in contact with water or soil.

CATION (CAT-EYE-en) CATION

A positively charged ion in an electrolyte solution, attracted to the cathode under the influence of a difference in electrical potential. Sodium ion (Na^+) is a cation.

CHELATION (key-LAY-shun) CHELATION

A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of metals (copper). Also see SEQUESTRATION.

COLIFORM (COAL-i-form) COLIFORM

A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm-blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic (disease-causing) organisms.

COLLOIDS (CALL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

COMPLETE TREATMENT COMPLETE TREATMENT

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration.

DECOMPOSITION DECOMPOSITION

The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) tends to produce much less objectionable tastes and odors.

DENSITY (DEN-sit-tee) DENSITY

A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DESTRATIFICATION (de-STRAT-uh-fuh-KAY-shun) DESTRATIFICATION

The development of vertical mixing within a reservoir to eliminate (either totally or partially) separate layers (of temperature, plant, or animal life) in a lake or reservoir. This vertical mixing can be caused by mechanical means (pumps) or through the use of forced air diffusers which release air into the lower layers of the reservoir.

DETENTION TIME DETENTION TIME

(1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow.

(2) The actual time in hours, minutes or seconds a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber. In storage reservoirs, detention time is the length of time entering water will be held before being drafted for use (several weeks to years, several months being typical.)

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid (box-like) internal structure consisting mainly of silica.

DIMICTIC (die-MICK-tick) DIMICTIC

Lakes and reservoirs which freeze over and normally go through two stratification and two mixing cycles within a year.

DIRECT FILTRATION DIRECT FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted.

ELECTROLYTE (ee-LECK-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

EPILIMNION (EP-uh-LIM-knee-on) EPILIMNION

The upper layer of water in a thermally stratified lake or reservoir. This consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

EUTROPHIC (you-TRO-fick) EUTROPHIC

Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.

EUTROPHICATION (you-TRO-fi-KAY-shun) EUTROPHICATION

The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.

EVAPOTRANSPIRATION (ee-VAP-o-TRANS-purr-A-shun) EVAPOTRANSPIRATION

The process by which water vapor passes into the atmosphere from living plants.

FLUSHING FLUSHING

A method used to clean water distribution lines. Hydrants are opened and water with a high velocity flows through the pipes, removes deposits from the pipes, and flows out the hydrants.

HEAD HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

HYPOLIMNION (HI-poe-LIM-knee-on) HYPOLIMNION

The lowest layer in a thermally stratified lake or reservoir. This layer consists of colder, more dense water, has a constant temperature and no mixing occurs.

INORGANIC INORGANIC

Material such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

LITTORAL ZONE (LIT-or-al) LITTORAL ZONE

(1) That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants.

(2) The strip of land along the shoreline between the high and low water levels.

MESOTROPHIC (MESS-o-TRO-fick) MESOTROPHIC

Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

METALIMNION (MET-uh-LIM-knee-on) METALIMNION

The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the THERMOCLINE.

METHYL ORANGE ALKALINITY METHYL ORANGE ALKALINITY

A measure of the total alkalinity in a water sample. The alkalinity is measured by the amount of standard sulfuric acid required to lower the pH of the water to a pH level of 4.5, as indicated by the change in color of methyl orange from orange to pink. Methyl orange alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

MILLIGRAMS PER LITER, mg/*L* MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/*L* of a substance in fresh water is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams or 10 milligrams per liter (10 mg/*L*), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).

MONOMICTIC (mo-no-MICK-tick) MONOMICTIC

Lakes and reservoirs which are relatively deep, do not freeze over during the winter months, and undergo a single stratification and mixing cycle during the year. These lakes and reservoirs usually become destratified, then followed by the mixing cycle, in the fall of the year.

NUTRIENT NUTRIENT

Any substance that is assimilated (taken in) by organisms and promotes growth. Nitrogen and phosphorus are nutrients which promote the growth of algae. There are other essential and trace elements which are also considered nutrients.

OLIGOTROPHIC (AH-lig-o-TRO-fick) OLIGOTROPHIC

Reservoirs and lakes which are nutrient poor and contain little aquatic plant or animal life.

ORGANIC ORGANIC

Substances which come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

OVERTURN OVERTURN

The almost spontaneous mixing of all layers of water in a reservoir or lake when the water temperature becomes similar from top to bottom. This may occur in the fall/winter when the surface waters cool to the same temperature as the bottom waters and also in the spring when the surface waters warm after the ice melts.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

PERIPHYTON (puh-RIF-uh-tawn) PERIPHYTON

Microscopic plants and animals that are firmly attached to solid surfaces under water such as rocks, logs, pilings and other structures.

pH (pronounce as separate letters) pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$pH = \log \frac{1}{(H^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

PHOTOSYNTHESIS (foe-tow-SIN-thuh-SIS) PHOTOSYNTHESIS

A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen and additional plant material, using sunlight for energy. All green plants grow by this process.

PHYTOPLANKTON (FI-tow-PLANK-ton) PHYTOPLANKTON

Small, usually microscopic plants (such as algae), found in lakes, reservoirs, and other bodies of water.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters. These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they *MUST* be present in order for THMs to form.

REAERATION (RE-air-A-shun) REAERATION

The introduction of air through forced air diffusers into the lower layers of the reservoir. As the air bubbles form and rise through the water, oxygen from the air dissolves into the water and replenishes the dissolved oxygen. Also the rising bubbles cause the lower waters to rise to the surface where oxygen from the atmosphere is transferred to the water. This is sometimes called surface reaeration.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

REDUCTION (RE-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

SECCHI DISC (SECK-key) SECCHI DISC

A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.

SEPTIC (SEP-tick) SEPTIC

A condition produced by bacteria when all oxygen supplies are depleted. If severe, bottom deposits and water turn black, give off foul odors, and the water has a greatly increased chlorine demand.

SEWAGE SEWAGE

The used water and solids that flow from homes through sewers to a wastewater treatment plant. The preferred term is WASTEWATER.

STRATIFICATION (STRAT-uh-fuh-KAY-shun) STRATIFICATION

The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature. Also see THERMAL STRATIFICATION.

THERMAL STRATIFICATION (STRAT-uh-fuh-KAY-shun) THERMAL STRATIFICATION

The formation of layers of different temperatures in a lake or reservoir. Also see STRATIFICATION.

THERMOCLINE (THUR-moe-KLINE) THERMOCLINE

The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in termperature with depth. Also called the METALIMNION.

THRESHOLD ODOR THRESHOLD ODOR

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called ODOR THRESHOLD.

THRESHOLD ODOR NUMBER THRESHOLD ODOR NUMBER

TON. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

WASTEWATER WASTEWATER

The used water and solids from a community (including used water from industrial processes) that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a wastewater treatment plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "WASTEWATER."

ZOOPLANKTON (ZOE-PLANK-ton) ZOOPLANKTON

Small, usually microscopic animals (such as protozoans), found in lakes and reservoirs.

CHAPTER 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

(Lesson 1 of 2 Lessons)

3.0 IMPORTANCE OF RESERVOIR WATER QUALITY MANAGEMENT

3.00 Use of Surface Reservoirs (Impoundments) as Domestic Water Supplies

During the past few decades, more and more people in both cities and rural areas have become either partially or wholly dependent on surface reservoirs and lakes as a source for their water supplies. As populations have increased, domestic, municipal, industrial, recreational, and agricultural water usage has also increased, creating demands on water supplies that cannot be met directly by groundwater or surface water diversions from streams and rivers.

These increased demands have been met for the most part by constructing dams and reservoirs which provide carry-over storage for excess runoff and provide a dependable water supply during the dry season of the year and during periods of prolonged drought. Particularly in the western United States, a majority of the major cities receive domestic water from surface lakes and reservoirs. In most cases the water is stored in one or more major reservoirs before it is delivered to the consumers. In those areas which do depend directly on local water supplies, there may be several large reservoirs which capture runoff from local watersheds and store it for future use.

The capacities of reservoirs used as domestic water supplies range from less than 100 acre feet to several million acre feet. The time water may be stored ranges from weeks or months to several years.

Methods of managing lakes and reservoirs used for domestic water supplies vary widely depending on local situations. In addition to serving domestic water needs, a reservoir may be used for flood control purposes, for hydroelectric power generation, for regulating downstream releases, for recreational purposes, or for providing water for agricultural, municipal and industrial uses. The amount and type of public use allowed on reservoirs also varies widely according to individual situations. Some allow motor boats, some allow only boats without motors; most do not allow any body-contact water sports but some allow complete body-contact sports such as swimming and water skiing.

Small lakes in remote areas may be open for public use only a few days each year while large lakes and reservoirs located near metropolitan areas may accommodate several million visitors annually. The methods of treating water supplies from reservoirs range from disinfection only, to *DIRECT FILTRATION*,[1] to *COMPLETE TREATMENT*[2] which may even include softening and activated carbon filtration. Each reservoir should have a water quality management program which is designed to meet the reservoir's individual requirements.

3.01 Factors Affecting Water Quality

Water quality within lakes and reservoirs is influenced and controlled by many factors. Of major concern is the fact that many of the conditions which adversely affect water quality in domestic water supply reservoirs result from man's use of the environment. In order to control and maintain water quality, man's activities must be controlled. The occurrence of acid rainfall is of concern in many areas of the United States and Europe. Pollution from both motor vehicles and industrial plants has increased the acidity of rain in some areas to the point that when runoff reaches lakes and reservoirs, the biological balance is severely affected. Fish die-offs are obvious and easily detected but other biological upsets or trends may not be so obvious.

The impacts of man's activities within a given reservoir's drainage area are also a major concern. Wastewater, agricultural runoff, grazing of livestock, drainage from mining areas, runoff from urban areas, and industrial discharges may all lead to deterioration in physical, chemical, or biological water quality within a reservoir. Increased turbidity and siltation may result from man's farming practices, fires, and logging operations. If not properly controlled, public use of a reservoir may result in reduced water quality.

Natural factors which may affect the quality of water in a given lake or reservoir include the following:

---

[1] *Direct Filtration. A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted.*

[2] *Complete Treatment. A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration.*

1. Climate: temperature, intensity and direction of wind movements, type, pattern, intensity and duration of precipitation;

2. Watershed and Drainage Areas: geology, topography, type and extent of vegetation, and use by native animals;
3. Wildfires (caused by lightning); and
4. Reservoir Area: geology, land form including depth, area, and bottom topography, and plant growth at the time the reservoir is filled.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 85.

3.0A List two common sources of water other than lakes or reservoirs.

3.0B What methods are used to treat domestic water delivered from water supply reservoirs?

3.0C How does man's presence cause deterioration of water quality in reservoirs?

3.0D What natural factors may result in lowered water quality degradation in reservoirs?

3.1 CAUSES OF WATER QUALITY PROBLEMS

3.10 Nutrients[3]

Many water quality problems in domestic water supply reservoirs occur in reservoirs containing moderate or large quantities of nutrients such as phosphate, nitrate, and organic nitrogen compounds. These nutrients may act as a fertilizer in a lake to stimulate the growth of algae just as they stimulate growth on a lawn, garden, or orchard. Reservoirs and lakes which are rich in nutrients and thus very productive in terms of aquatic animal and plant life are commonly referred to as eutrophic (you-TRO-fick). Reservoirs which are nutrient-poor and contain little plant or animal life are classed as oligotrophic (AH-log-o-TRO-fick). Between these two types of reservoirs are mesotrophic (MESS-o-TRO-fick) reservoirs containing moderate amounts of nutrients able to support moderate levels of plant and animal life.

In productive reservoirs aquatic plants such as pondweeds, water hyacinths, tules, and sedges may be abundant in the shallow water or *LITTORAL ZONES*[4] (Figure 3.1). Productive lakes usually support large populations of phytoplankton (very small plants) and/or zooplankton (very small animals) at various times during the year. A sudden large increase in plankton populations is commonly referred to as a "bloom." Phytoplankton blooms in particular are referred to as "algal blooms" (pronounced AL-gull). The duration and the amount of population growth of an individual algal bloom depends upon various environmental factors including light,

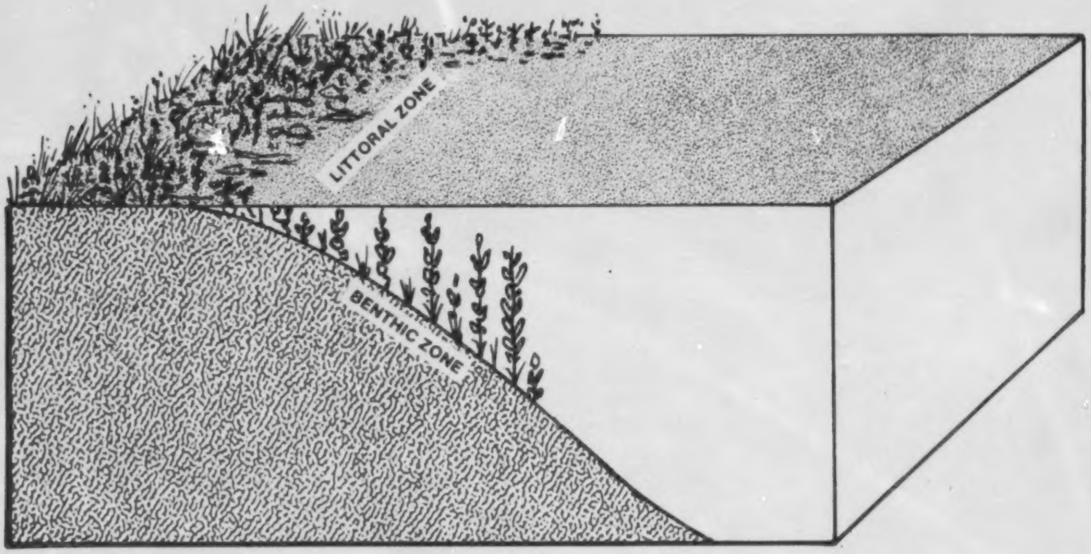

Fig. 3.1 Littoral zone

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[3] *Nutrient. Any substance that is assimilated (taken in) by organisms and promotes growth. Nitrogen and phosphorus are nutrients which promote the growth of algae. There are other essential and trace elements which are also considered nutrients.*

[4] *Littoral Zone (LIT-o-ral). (1) That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants. (2) The strip of land along the shoreline between the high and low water levels.*

temperature, and nutrient conditions. An individual bloom may contain from one to several types of algae and may last from a few days to several weeks or even months.

3.11 Algal Blooms

Several common water quality problems in domestic water supply reservoirs may be related to algal blooms. These problems will be discussed individually but are summarized as follows:

1. Taste and odor problems,
2. Shortened filter runs of complete treatment plants,
3. Increased pH (which reduces chlorination efficiency),
4. Dissolved oxygen depletion, and
5. Organic loading.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 85.

3.1A Large quantities of what nutrients are undesirable in a water supply reservoir?

3.1B List the three classes of reservoirs based on nutrient content and productivity in terms of aquatic animal and plant life.

3.1C What is an "algal bloom?"

3.12 Tastes and Odors

Objectionable tastes and odors in the domestic water supply are often related to the occurrence of algal blooms. The nature of these tastes and odors is related to the particular type of algae but may change as the intensity of the algal bloom changes. For example, some algae produce a grassy odor when populations are moderate, but a much more intense odor described as a septic or pig pen odor when populations are large or dying and decaying. Among the more common types of tastes and odors produced by algae are the following: fishy, aromatic, grassy, septic, musty, and earthy. Approximately forty types of algae have been identified as taste and odor producers. The extent of taste and odor problems caused by algal blooms ranges from slight consumer objection to total rejection of the supply for domestic uses. Taste complaints often arise when the water is used for drinking or for making coffee or tea because objectionable tastes seem to be more noticeable when the water is at room temperature and above than when the water is cold. Odors are frequently most noticeable when the hot water supply is in use, particularly when it is used for showers, cooking and dishwashing.

In many situations, chlorination of the water supply reduces the level of tastes and odors; however, there are some instances in which the tastes and odors appear to be stronger following chlorination. Water treatment costs increase significantly when tastes and odors must be removed. Fortunately many conventional plants are capable of reducing or eliminating tastes and odors when properly operated.

Stratification of reservoirs into thermal layers, as a result of climatic conditions, will be discussed in detail in Section 3.17, "Thermal Stratification." In connection with algae, however, tastes and odors are usually strongest in the thermal layer of the reservoir where the bloom occurs. In most cases, this takes place within the upper layer of water. Figure 3.2[5] illustrates this fact by showing *THRESHOLD ODOR*[6] profiles during three separate algal blooms in Lake Casitas, California. These blooms occurred when thermal stratification existed. The odors (represented by higher TON readings) are concentrated within the upper, warmer layer of water and they have not been mixed into the deeper colder layers to any significant extent.

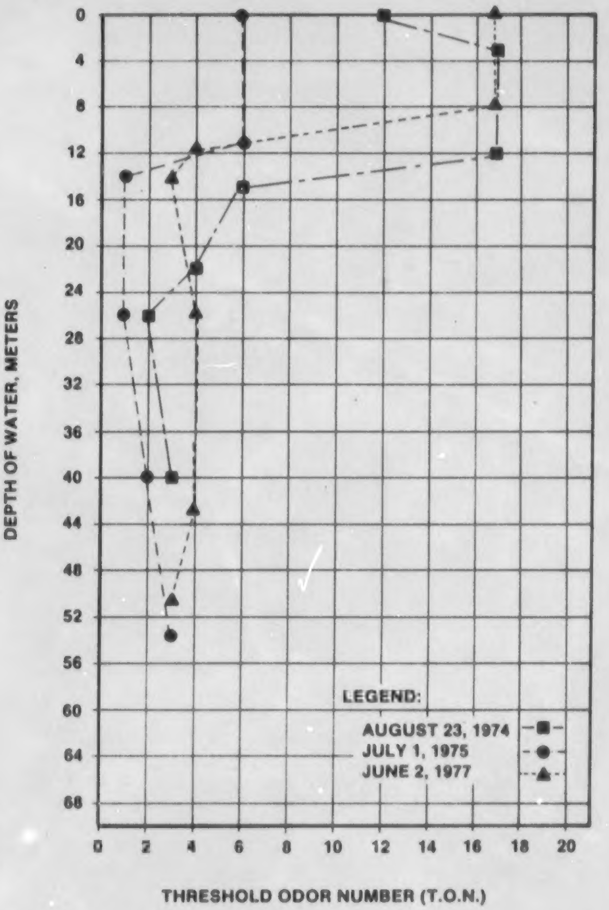

Fig. 3.2 Lake Casitas odor profiles

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[5] *Figure 3.2 was prepared by taking a boat out onto Lake Casitas on the three dates shown. A water sampler was lowered into the Lake at various depths, a sample collected, and then analyzed to determine the threshold odor number (TON). The odor profile drawing was prepared by marking a plotting point at each depth (on the left side) at the measured TON (across the bottom). The plotting points for each day were connected to produce the "odor profiles."*

[6] *Threshold Odor. The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called odor threshold.*

A problem that has been noted in several Southern California domestic water supply reservoirs is that when the fall *OVERTURN*[7] occurs, obnoxious tastes and odors are brought downward from the upper portion of the reservoir and mixed throughout the entire body of water. Even using multi-level intakes (water inlets), it is not possible to select a depth where taste and odor problems are minimized. In lakes and reservoirs which freeze over during winter months, algal blooms (late algae) have been known to occur underneath the ice, causing taste and odor problems in the deeper waters.

Considerable research has been devoted to identifying taste and odor problems which result from blooms of free-floating (planktonic) algae. To identify algae species and estimate population levels, water samples are collected either with or without the aid of various types of plankton nets (Figure 3.3). Samples are then examined in the laboratory using standard procedures. Research has shown that algae which are growing attached (periphyton) to bottom sediments and structures or submerged plants can be a major contributor to taste and odor problems. These algal growths cannot be sampled and evaluated by conventional methods, so trained scuba divers collect samples and map the extent of algal growths.

One species of blue-green algae in particular, *OSCILLATORIA CURVICEPS*,[8] has been identified as being responsible for certain earthy, musty tastes and odors. Considerable research is also underway throughout the United States to identify and quantify organic compounds which cause taste and odor and to link a particular compound to the species of algae which produces it. Two compounds, Geosmin and Methylisoborneal (MIB) which have been linked to earthy, musty tastes and odors, bring consumer complaints when they are present in the water supply in concentrations as low as a few parts per trillion (nanograms per liter).

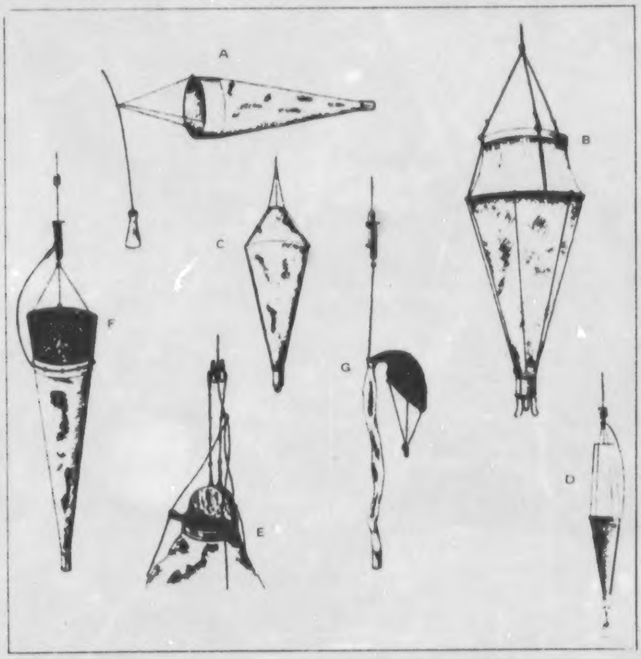
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 85.

3.1D What types of tastes and odors are produced by algae?

3.1E How can chlorine affect tastes and odors?

3.1F Where are tastes and odors found in reservoirs?



(A) Simple conical tow-net; (B) Hensen net; (C) Apstein net; (D) Juday net; (E) Apstein net with semicircular closing lids; (F) Nansen closing net, open; (G) Nansen closing net, closed.

Fig. 3.3 Plankton sampling nets

(Reprinted from STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 15th Edition, American Public Health Association, Washington, D.C., 1980, by permission of the American Public Health Association)

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[7] *Overturn. The almost spontaneous mixing of all layers of water in a reservoir or lake when the water temperature becomes similar from top to bottom. This may occur in the fall/winter when the surface waters cool to the same temperature as the bottom waters and also in the spring when the surface waters warm after the ice melts.*

[8] *See STANDARD METHODS FOR EXAMINATION OF WATER AND WASTEWATER, 15th Edition, Color Plates B and C, between pages 1072 and 1073. Available from Data Processing Department, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Price to members, $40.00; nonmembers $50.00.*

3.13 Shortened Filter Runs

A second major problem associated with algal blooms is that certain species of algae tend to clog filters at water treatment plants and thereby reduce both filtration rates and the duration of filter runs. Filter runs also may be shortened due to gases released by algae. Normal filter runs commonly extend from 30 to 100 hours before cleaning is required, while short filter runs caused by the presence of algae may be less than 10 hours in length. In extreme cases, the clogging may occur so frequently that the amount of water needed to backwash filters for cleaning is greater than the amount of water treated and sent to the distribution system.

Reduced filtration rates and increased frequency of filter backwashing are reflected in an inability to meet system water demands and increased water treatment costs.

3.14 Increased pH[9]

Algal blooms are often associated with marked fluctuations in pH of the water in the upper layer of the reservoir where blooms occur. The pH is frequently raised from a level near 7 to near 9 or above as a result of these blooms. Chlorination efficiency is greatly reduced at the higher pH levels. This increases water treatment costs because pH must be adjusted down, or more chlorine must be added. Since algae remove carbon dioxide from solution and convert it into cellular material as they grow, the carbonate equilibrium (balance) is affected. pH values as high as 9.8 can be reached where algae are in high concentrations and under favorable light conditions.

Increases and decreases in pH are caused by *PHOTOSYNTHESIS*[10] during daylight hours and respiration by algae during darkness. During the daylight hours the pH will increase, while the pH is lowered at night. Respiration by algae result in an increase in carbon dioxide in water (lowering of pH), while photosynthesis results in a decrease in carbon dioxide in the water (increasing of pH). These fluctuations in pH can adversely affect both the coagulation and disinfection treatment processes.

3.15 Dissolved Oxygen Depletion

As algal blooms progress, the dissolved oxygen content at depths where the bloom occurs normally increases markedly as a result of photosynthesis. Supersaturation of dissolved oxygen occurs when the dissolved oxygen exceeds the saturation value for the existing water temperature. Dissolved oxygen supersaturation in surface waters is common during major algal blooms.

When algal cells die, however, this abundant oxygen is used up by the bacteria that feed upon (metabolize) the algae cells. Following severe algal blooms, dissolved oxygen in both surface and deeper waters may be reduced to the point that fish kills occur. Fish kills due to low oxygen levels may also occur when there is a combination of extremely heavy algal bloom and a sudden reduction in the amount of sunlight available. Under these conditions, the photosynthetic activity of algae slows down. With less oxygen being produced, the algae use oxygen stored in the water for respiration. If this condition persists for a considerable length of time, the water may lose most of its oxygen, causing both the algae and the fish to die of oxygen starvation. Frequently fish kills from dead algae are the result of the algae clogging the gills of the fish.

Major fish die-offs in domestic water supply reservoirs nearly always generate complaints from the general public, particularly from those who use the water as a drinking supply. The cleanup and disposal of dead fish from a large reservoir can place a large financial and manpower burden on the water utility.

In stratified lakes, oxygen depletion in the colder, deeper waters often occurs following algal blooms. Water quality problems related to this condition will be included in the discussion on stratified lakes in Section 3.17, "Thermal Stratification."

3.16 Organic Loading

As a result of algal blooms, major increases in organic matter naturally occur within water supply reservoirs. The most notable impacts of this increased organic loading are increased color in the water supply and a major increase in chlorine demand. Solution of both of these problems is again reflected in increased water treatment costs.

The organic loading resulting from algal blooms is often associated with high *TRIHALOMETHANE*[11] levels following free residual chlorination (a water treatment disinfection process). The organic matter contains *THM PRECURSORS*[12] which react with the chlorine to form trihalomethanes. The U.S. Environmental Protection Agency (EPA) has adopted a maximum contaminant level (MCL) of 100 $\mu g/L$ (micrograms per liter) for trihalomethanes in domestic water supplies, based upon the average of quarterly samplings

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[9] *pH (pronounce as separate letters). pH is an expression of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.*

$$pH = \log \frac{1}{(H+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

[10] *Photosynthesis (foe-tow-SIN-thuh-sis). A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen and additional plant material, using sunlight for energy. All green plants grow by this process.*

[11] *Trihalomethanes (tri-HAL-o-METH-hanes). Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.*

[12] *THM Precursors. Natural organic compounds found in all surface and groundwaters. These compounds MAY react with halogens (such as chlorine) to form trihalomethanes (tri-HAL-o-METH-hanes) (THMs); they MUST be present in order for THMs to form.*

within the water distribution system. The EPA trihalomethane standards became effective in December 1981 for systems serving over 75,000 persons and in December 1983 for systems serving 10,000 to 75,000 persons.

Increased trihalomethane (THM) levels resulting from algal blooms may exceed the maximum contaminant levels (MCLs). Either a change in disinfection methods or use of activated carbon filtration will normally be required to lower THM levels to within acceptable limits. If either of these procedures is required, it will result in big increases in water treatment costs.

Two helpful references for identifying algae and the problems related to them are *ALGAE IN WATER SUPPLIES*[13] and *STANDARD METHODS.*[14]

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 85.

3.1G What problems do algae cause on filters?

3.1H What is the influence of algal blooms on pH?

3.1I What is the influence of algal blooms on dissolved oxygen?

3.1J Increased organic loadings from algal blooms can cause what kinds of water quality problems?

3.17 Thermal Stratification

Thermal stratification develops in lakes and reservoirs in the spring when the surface waters begin to warm. As summer approaches, the weather warms, the longer days mean longer periods of heating of the water by the sun's rays, and the brisk spring winds subside. Under these conditions the surface waters warm rapidly, expand, and become lighter than the lower waters. Although the wind may continue to blow, its contribution to mixing of the lake waters diminishes because of the resistance to mixing resulting from different water densities caused by the increased water temperatures. The greater the difference in water temperatures, the greater the difference in water densities which create the resistance to mixing. When layers of different temperatures occur within a lake, the lake is considered thermally stratified.

Another type of common water quality problem occurs in productive, thermally stratified reservoirs. Reservoirs and lakes within the United States generally fall into one of two classificaitons relative to annual thermal stratification cycles. Those relatively deep-water lakes and reservoirs which do not freeze over during winter months undergo a single stratification and destratification (mixing) cycle and are classed as "monomictic" (one mixing). In some areas lakes have one winter turnover that may last from September to mid-May (whenever the wind blows the lake turns over). Lakes and reservoirs which freeze over normally go through two stratification and destratification (mixing) cycles and are classed as "dimictic" (two mixings).

In a monomictic lake, water temperature during winter months is uniform (the same) from top to bottom; the water density throughout the lake is uniform; and the water is mixed only by wind currents. With continued cooling, the surface water becomes more dense and sinks to the bottom. As the season progresses into spring, the sun's rays warm the upper portion of the lake or reservoir faster than the deeper portion. The decrease in density of the warmer water on top slows the vertical mixing action within the lake and a barrier is formed between the upper and lower layers. The upper layer which continues mixing is known as the EPILIMNION (EP-uh-LIM-knee-on) (Figure 3.4). The middle layer is the zone of rapid temperature decrease with depth and is called the THERMOCLINE (THUR-moe-KLINE) or METALIMNION (MET-uh-LIM-knee-on). The lowest layer of colder, more dense water is the HYPOLIMNION (HI-poe-LIM-knee-on). When these conditions exist, the lake is said to be thermally stratified. The lake remains in this stratified or layered condition through the summer and into the fall or early winter when the surface waters become as cool as deeper waters, the density barrier is broken, and destratification or mixing ("turnover") takes place. Figure 3.5 illustrates the thermal stratification cycle in a monomictic (single mixing cycle) lake by showing average temperature profiles in Lake Casitas on January 1, April 25, August 15, and October 25 for the period 1962 through 1967.

Once thermal stratification occurs and natural mixing ceases in the metalimnion (middle) and hypolimnion (lower) zones of a productive lake, major changes in water quality begin to take place. *BIOCHEMICAL OXYGEN DEMAND*[15] within the metalimnion and hypolimnion may lead to total dissolved oxygen depletion, resulting in *ANAEROBIC*[16] conditions within these zones. Major contributors to the biochemical oxygen demand are the organisms that decompose dead algal cells as they fall into these zones. Depending upon specific conditions, oxygen depletion may

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[13] ALGAE IN WATER SUPPLIES — An Illustrated Manual on the Identification, Significance and Control of Algae in Water Supplies, by C. Mervin Palmer, U.S. Public Health Service Publication No. 657, reprinted 1962. Available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Stock Number 55-001-01081-8. Price $4.00.

[14] STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 15th Edition. See Section 1007, Identification of Aquatic Organisms, D. Key for Identification of Freshwater Algae Common in Water Supplies and Polluted Waters (Color Plates A-F). Available from AWWA, Data Processing Department, 6666 West Quincy Avenue, Denver, Colorado 80235. Price for members, $40.00; nonmembers, $50.00.

[15] Biochemical Oxygen Demand. BOD. The rate at which microrganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

[16] Anaerobic (AN-air-O-bick). A condition in which "free" (atmospheric) or dissolved oxygen is NOT present in water.

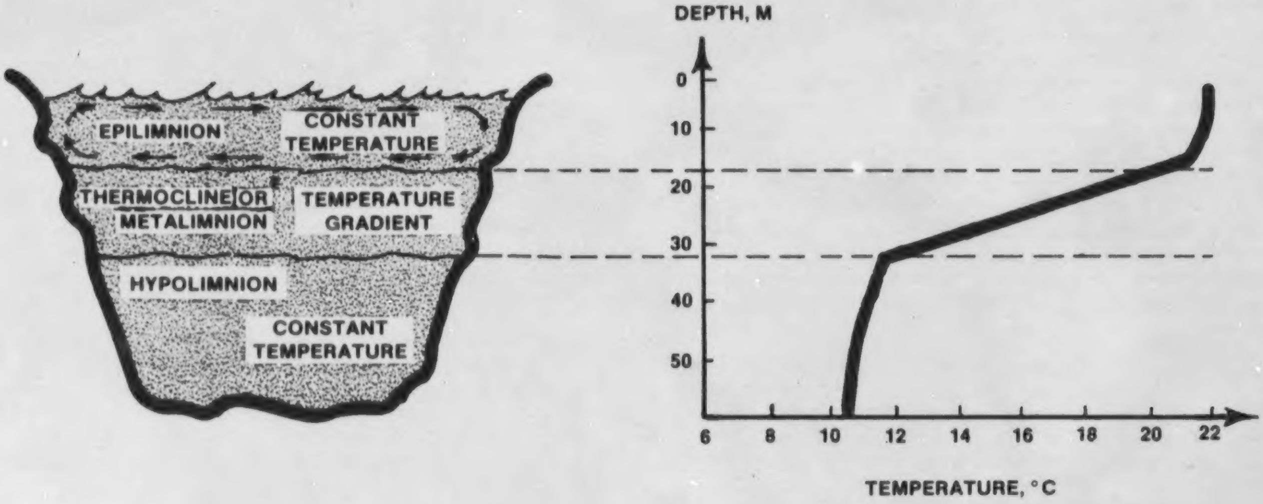
EPILIMNION
CONSTANT TEMPERATURE
THERMOCLINE OR METALIMNION
TEMPERATURE GRADIENT
HYPOLIMNION
CONSTANT TEMPERATURE
DEPTH, M
0
10
20
30
40
50
6
8
10
12
14
16
18
20
22
TEMPERATURE, °C

Fig. 3.4 Thermally stratified lake or reservoir

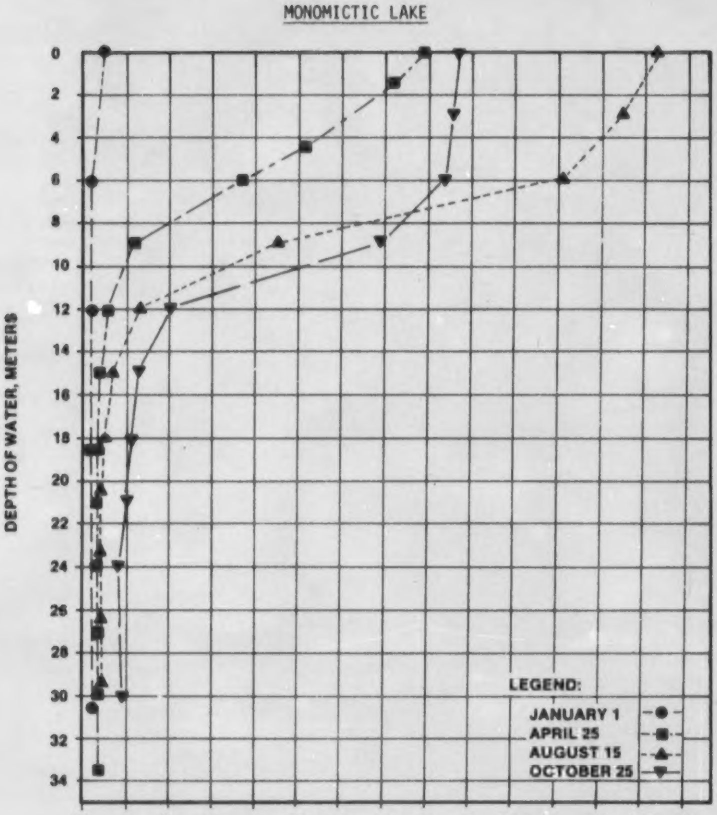

Fig. 3.5 Average temperature profiles in Lake Casitas on January 1, April 25, August 15, and October 25 for period 1962 through 1967

be completed in a few weeks or anytime up to several months after thermal stratification begins. When the hypolimnion becomes anaerobic, it usually remains so until the reservoir turnover (destratification) occurs in late fall or early winter. Figure 3.6 illustrates the progress of dissolved oxygen stratification in monomictic Lake Cachuma, California, during 1980. Dissolved oxygen profiles are shown on April 20, June 14, September 20, and December 13. Note that by December 13, reservoir turnover (destratification) had occurred and dissolved oxygen content was nearly uniform from top to bottom.

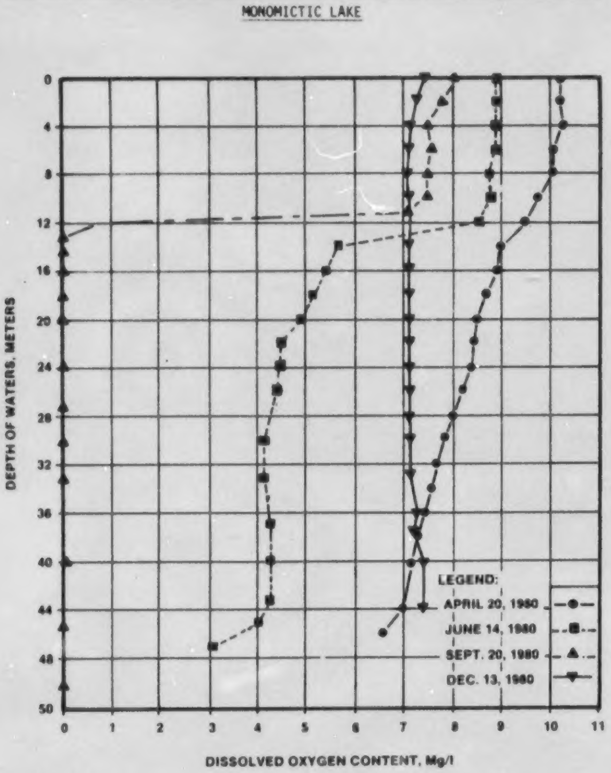

Fig. 3.6 Dissolved oxygen profiles in Lake Cachuma on April 20, June 14, September 20, and December 13, 1980

An easy way to measure the temperature profile in a thermally stratified lake or reservoir during the summer is to use a maximum-minimum thermometer. Lower the thermometer to various depths from top to bottom. The minimum temperature is the water temperature at each depth.

3.18 Anaerobic Conditions

When anaerobic conditions exist in either the metalimnion or hypolimnion of a stratified lake or reservoir, water quality problems may make the water unappealing for domestic use without costly water treatment procedures. Most of these problems are associated with *REDUCTION*[17] in the stratified waters. The first notable problem may be the presence of a strong rotten egg odor in waters drawn from the anaerobic zone. This odor usually indicates the presence of hydrogen sulfide (H_2S) which occurs as sulfate and is reduced to sulfide within the anaerobic bottom sediments. The reduction to H_2S is brought about by certain anaerobic bacteria. Another group of sulfate-reducing bacteria are capable of producing H_2S by attacking organic matter and liberating (freeing) H_2S from protein material. The presence of hydrogen sulfide in domestic water supplies is generally unacceptable to consumers.

A second major problem in anaerobic water occurs when iron and/or manganese exist in bottom sediments in the reduced state and pass into solution. The presence of either iron or manganese in appreciable quantities within the domestic supply can lead to major "dirty water" problems. In addition to appearing reddish, brown, or just plain dirty, the water may stain clothes during washing and stain porcelain fixtures such as sinks, bathtubs, and toilet bowls. The color or staining occurs as a result of the iron and/or manganese being changed into the oxidized state *AFTER* it enters the distribution system. *OXIDATION*[18] may occur during disinfection (chlorine is a strong oxidant) or within tanks and reservoirs when the water becomes aerated. Water containing either iron or manganese in quantities exceeding the maximum containment levels (MCL) listed in Federal Secondary Drinking Water Standards is generally unacceptable to consumers (iron, 0.3 mg/*L*[19] and manganese, 0.05 mg/*L*). If iron or manganese accumulates in the distribution system, extensive *FLUSHING*[20] is required in order to clean out the system.

When significant levels of dissolved oxygen are present, iron and manganese exist in an oxidized state and normally precipitate into the reservoir bottom sediments. Under reducing conditions, however, iron is changed from the oxidized ferric state into the soluble ferrous state, and manganese changes from the oxidized manganic state into the soluble manganous state. Once either or both of these metals pass into solution within the anaerobic zones, they remain there until reservoir turnover occurs and they are oxidized and again *PRECIPITATE*[21] into the bottom sediments. When a lake or reservoir becomes anaerobic, manganese normally passes into solution earlier than iron. Following turnover, manganese usually precipitates out after the iron has precipitated.

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[17] *Reduction (re-DUCK-shun). Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions in water, sulfate compounds or elemental sulfur are reduced to odor-producing hydrogen sulfide (H_2S) or other compounds. The opposite of OXIDATION.*

[18] *Oxidation (ox-uh-DAY-shun). Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.*

[19] *mg/L, Milligrams Per Liter. A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/L is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one mllion milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/L), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).*

[20] *Flushing. A method used to clean water distribution lines. Hydrants are opened and water with a high velocity flows through the pipes, removes deposits from the pipes, and flows out the hydrants.*

In summary, it is often difficult if not impossible to select a level from which to draw acceptable domestic water in a monomictic, productive lake during summer and fall months when thermal stratification exists. Water in the upper levels may contain high quantities of taste- and odor-causing compounds, unacceptably warm water, high organic content and much higher than desired pH. The deeper, cooler water may not be acceptable due to the presence of hydrogen sulfide gas, iron and manganese, or other problems related to anaerobic conditions.

Water quality problems within dimictic lakes and reservoirs may be similar to those which occur in monomictic, except that instead of occurring primarily during summer and fall months, they may also exist during winter months. Water normally reaches its greatest density at 4°C. As the freezing point of water is near 0°C, the ice-covered upper, colder water is less dense than deeper, slightly warmer waters. This condition results in thermal stratification during periods when surface water temperatures fall below 4°C. In addition to the normal fall turnover which occurs in monomictic lakes, a second turnover takes place following the spring thaw. When the surface waters warm up to 4°C they are more dense than the deeper, warmer waters and turnover takes place once again. Anaerobic conditions and their related water quality problems may exist in these lakes and reservoirs during most of the winter months as well as during summer and fall months.

3.19 Watershed Conditions

Domestic water supply reservoirs may at times experience major problems with water quality as a result of conditions within the drainage area or watershed in combination with climatic conditions. In many areas of the United States, the major portion of surface runoff into a reservoir occurs during a very short period of time. In semi-arid areas such as the Southwest, 75 percent or more of the annual runoff may occur as a result of only three or four major storms. Most runoff from these storms occurs within a few days during and following the storm. Likewise, in mountainous areas where snowmelt is the major source of runoff, most of the inflow occurs within a relatively short period of time during and following the spring snowmelt. Reservoirs subject to these conditions may experience sudden and dramatic increases in *TURBIDITY*[22], nutrient loading, and organic loading depending upon geological, topographical and vegetative conditions within the watershed.

Turbidity problems which occur during and following periods of major runoff are reflected in reduced rates of flow through the filters and shortened filter runs at water treatment plants. At reservoirs which do not filter water prior to service to consumers, Federal and state maximum allowable turbidity levels may be exceeded. The length of time that turbidity will affect water quality and water treatment practices depends on the extent of turbidity loading which occurs, mixing in the reservoir as a result of wind and other currents, and the nature of the particles causing turbidity. Larger suspended particles, such as sand and silt, may settle out within a few days or weeks; colloids, such as fine clays, may cause problems for an extended period of time. When storm waters are colder than reservoir waters, the high turbidity storm water sometimes flows into the reservoir underneath the warmer reservoir waters. This can cause the greatest turbidity increases to occur within the deeper zones. Within a few days, mixing takes place and turbidity becomes fairly uniform throughout the reservoir. Later, suspended particles begin to settle out and the waters within the upper zones show the least turbidity while the deepest waters have the greatest.

Increased levels of turbidity are a serious concern for water treatment plant operators because increased turbidity has a high chlorine demand. This could result in a decreased chlorine residual and an increasing possibility of bacterial contamination if the operator is not alert. An outbreak of "Giardia Lambia" (Giardiasis) occurred in Pennsylvania when a small reservoir "turned over" and high turbidity conditions developed.

Nutrient loading of a reservoir from its drainage area may result in increased productivity (algal blooms). This tends to occur during wet years when increased runoff raises the nutrient loading in the reservoir.

In watersheds containing large quantities of vegetation such as chaparral, it has been noted that there is an increase in organic loading and in associated THM precursors immediately following periods of major runoff. This condition appears to be related to the large quantities of organic material which is associated with the vegetation. Figure 3.7 illustrates total potential trihalomethane content[23] in Lake Casitas at various depths during the periods of August 1977 to January 1979 and March 1980 to August 1981. The dramatic increases in total potential trihalomethane content during the period of January through April, 1978, is associated with the unusually wet winter of 1978. Following the end of the runoff season, the total potential trihalomethane content dropped substantially. The summertime increases in total potential trihalomethane levels are most likely a result of increased organic loading during algal blooms.

Water quality improvement programs should be designed to evaluate water quality problems and their causes within a given lake or reservoir. Since no two reservoirs or lakes are exactly alike, each one will require a water quality improvement program prepared specifically for its individual situation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 85 and 86.

3.1K When a lake warms in the spring or summer, how does the decrease in density of the warmer surface water influence mixing action within the lake?

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[21] *Precipitate (pre-SIP-uh-tate). (1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid. (2) The separation from solution of an insoluble substance.*

[22] *Turbidity. The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.*

[23] *Total potential trihalomethane content was determined by attempting to duplicate actual Lake Casitas conditions in the laboratory. Lake samples were collected at various depths, a 3 mg/L chlorine dose was added to each sample, the sample was stored for 100 hours, and then the sample was analyzed for trihalomethanes.*

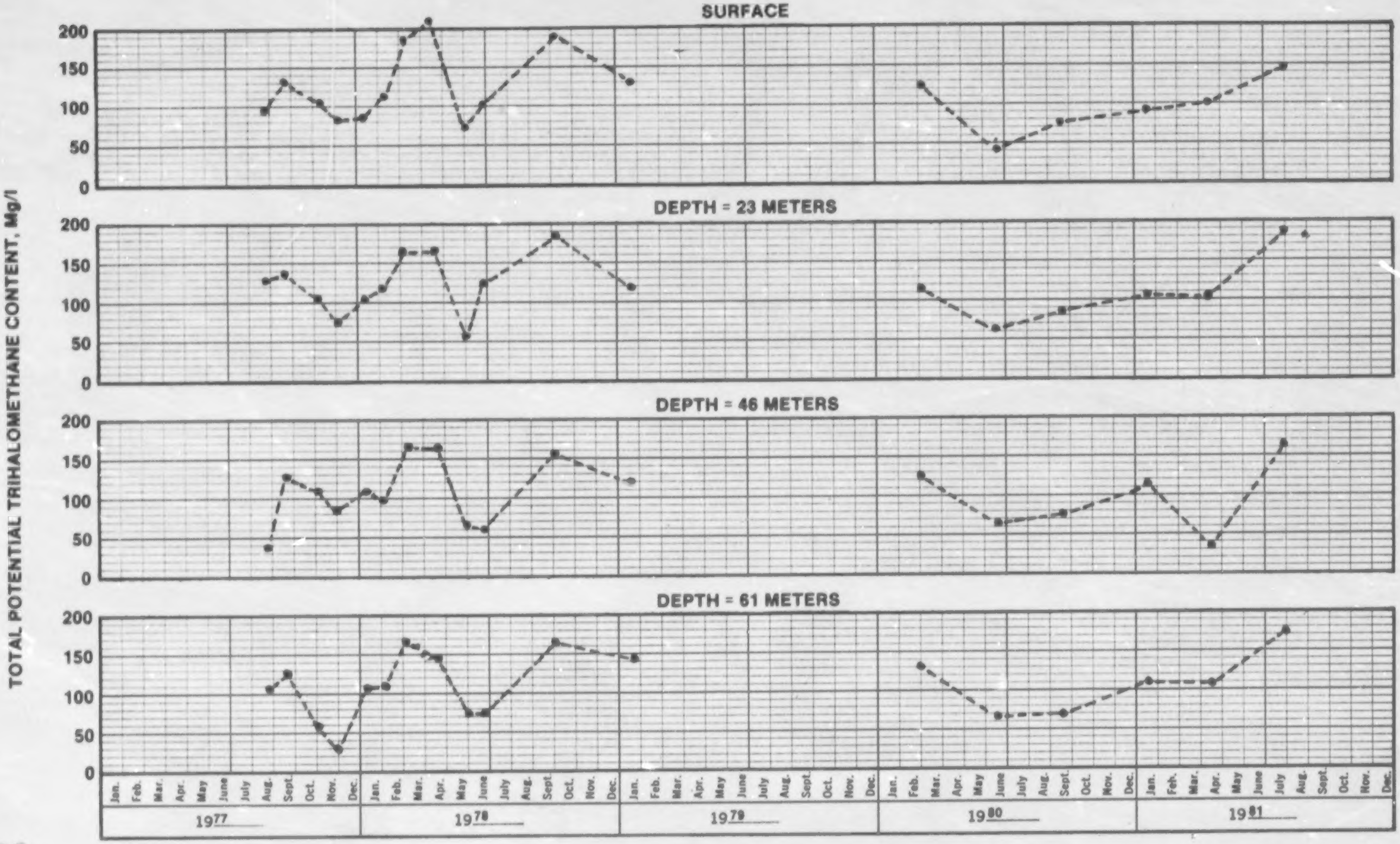

Fig. 3.7 *Lake Casitas — Total potential trihalomethane content at various depths*

3.1L How soon may oxygen depletion be completed after thermal stratification occurs?

3.1M What problems are caused by anaerobic conditions in reservoirs?

3.1N What problems can occur in reservoirs that experience large inflows during short periods?

3.2 PURPOSES OF RESERVOIR MANAGEMENT PROGRAMS

3.20 Improvement and Maintenance of Water Quality

Water quality management programs can be a very effective tool for controlling water quality problems in domestic water supply lakes and reservoirs. By evaluating the water quality problems which occur in a given reservoir and the various water quality management and control alternatives available, it may be possible to design a program to eliminate or at least control most problems within acceptable limits. During recent years, great progress has been made toward managing water quality within productive and eutrophic lakes and reservoirs. In many cases it has been possible to control the frequency and intensity of algal blooms and the water quality effects associated with these blooms. Frequently dissolved oxygen depletion can be controlled or eliminated within the metalimnion and hypolimnion, thereby eliminating or controlling iron, manganese and hydrogen sulfide problems.

Properly designed water quality management programs can also be effective in controlling silt loading, turbidity levels, nutrient loading, and organic loading in many water supply reservoirs. The actual procedures for preparing water quality management programs are discussed in the remainder of this lesson. In order to be feasible, water quality management programs must be prepared for each specific reservoir and be economically as well as technically justifiable.

3.21 Reduction of Water Treatment Costs

Operation, maintenance and capital costs of water treatment facilities have all increased drastically during recent years. Proper management of water quality within the reservoir can prove to be an effective tool in controlling these costs. Cost savings may be realized through increased length of filter runs, reduced chemical costs and alternative treatment methods. For example, if taste and odor problems and organic loading are controlled within the reservoir, the need for activated carbon treatment at the plant may be reduced or eliminated. By controlling algal blooms and silt loading, it may be possible to consider using direct filtration only instead of complete treatment. Iron and manganese control or removal within the treatment plant may not be necessary if levels are controlled within the reservoir. Cost savings must be evaluated on an individual basis, but may range from a few dollars to tens of dollars per million gallons treated. Major savings of hundreds of thousands to millions of dollars may be realized if capital costs for facilities such as sedimentation basins and activated carbon filters can be eliminated.

3.22 Improvement and Maintenance of Fishery and Recreational Values

In productive reservoirs and lakes where dissolved oxygen depletion occurs within the metalimnion and hypolimnion during summer and fall months, fish are forced to move into the warmer waters of the epilimnion. This not only reduces the size of habitat available to fish, but it may also limit the number of species which exist within a given lake or reservoir. In many areas of the United States, summer temperatures within the epilimnion reach maximums of 75 to 80°F (24 to 27°C). Cold water species of fish such as trout and salmon may not survive at these temperatures. If the deeper, colder waters can be prevented from becoming oxygen depleted, both warm and cold water species of fish can be maintained throughout the year.

Proper reservoir management techniques can prevent or minimize fish kills. Reduction in the intensity and severity of algal blooms reduces the hazard of fish kills as a result of rapid oxygen depletion or clogging of their gills with algae. Fish kills which occur in frozen lakes as a result of dissolved oxygen depletion in waters beneath the ice may also be reduced or eliminated by proper management techniques.

Proper lake management naturally results in increased appeal of the reservoir for recreational purposes. Recreational values are also increased when algae problems are reduced. Large mats and scums of algae are unappealing to swimmers, bathers and water skiers. Objectionable odors associated with these blooms reduce the reservoir area's appeal as a site for camping and picnicking. Property values around the edge of a lake or reservoir may increase significantly when major algae problems are reduced or eliminated.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 86.

3.2A What reservoir water quality problems can be controlled or eliminated by reservoir management programs?

3.2B How can reservoir management programs reduce water treatment costs?

3.2C What happens to trout and salmon when dissolved oxygen depletion occurs within the metalimnion and hypolimnion during summer and fall months?

3.3 METHODS OF RESERVOIR MANAGEMENT

3.30 Removal of Trees and Brush from Areas to be Flooded

In areas where new reservoirs are to be formed for the purpose of providing domestic water supplies by construction of dams or other means, it is often advisable to remove trees and brush from the areas to be flooded. The purpose of vegetation removal is to reduce the organic and nutrient loading which the reservoir will receive as it fills.

If large quantities of trees, brush, and other vegetation is left within the reservoir site, organisms will decompose the material after the area is flooded. This will release nutrients and organic matter into reservoir waters. Organisms which decompose the vegetative material will consume dissolved oxygen, thereby increasing the rate of oxygen depletion when thermal stratification of the reservoir takes place. Nutrients which are released during decomposition may lead to more and bigger algal blooms. Organics released during decomposition may contribute to increased color, chlorine demand and trihalomethane levels following chlorination.

Removal of major vegetation from the reservoir area is best accomplished by mechanical means. Little is accomplished if the material is cut and left on site so that it can decompose by natural processes. When practical, trees can be cut for firewood or timber and the stumps removed mechanically. In some cases, wood is burned on the site and the ashes are removed from the area. In other cases trees, including stumps, are removed by mechanical means.

Brush can be removed by a single tractor or by two or more tractors operating parallel to each other with a large chain stretched between them.

Once vegetation removal is accomplished, regrowth must be controlled by mechanical means until the reservoir is filled. When the filling cycle is completed, reservoir levels will seldom be lowered long enough for major vegetation regrowth to occur.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 86.

3.3A Why should trees and brush be removed from areas to be flooded by reservoirs?

3.3B What water quality problems may be caused by organics released during the decomposition of vegetation covered by water in a reservoir?

3.3C How can vegetation be removed from a reservoir site?

3.31 Watershed Management

3.310 Need for Watershed Management

The primary purpose of any watershed management program should be to control, minimize or eliminate any practices within the watershed area that are harmful to water quality within the domestic water supply reservoir. In order for watershed management programs to be effective, they must be both technically and economically feasible. The general public must be convinced that they are getting their dollars' worth when investing in watershed management programs. If it is much less costly to cure a water quality problem with specific treatment procedures than it is to prevent the problem from occurring through watershed management, it may be difficult, and even unwise, to try to convince the public that watershed controls should be implemented. If factors such as aesthetic or recreational values of the reservoir are also affected by the reduced water quality, the public should be informed so that the value of the water resource from an aesthetic or recreational viewpoint can be evaluated. While the public is very dollar conscious, it is also sensitive to environmental issues and will support well-designed programs for protecting the environment.

Because of the tremendous differences in size, topography, vegetative conditions and state of development in watersheds, it is impossible to discuss methods of watershed management that would apply in all areas. As with reservoir management programs, each watershed management program should be designed on the basis of potential water quality problems which must be solved or prevented and the options available for solving or preventing them. In most cases, the best tool for managing watersheds is probably the regulatory process. Regulations and ordinances which control or eliminate practices within a watershed which are detrimental to water quality can be adopted as needed on a local, county, state or even Federal level. All types of practices which may have to be controlled within a given watershed are too numerous to discuss in detail, but the most common practices causing water quality problems and means of controlling them are discussed in the following sections.

3.311 Wastewater

Contamination of the domestic water reservoir by wastewater (sewage) can lead to water quality problems ranging from significant to severe. Two major types of problems may result from raw wastewater contamination: nutrient loading of the lake or reservoir and microbiological contamination. In some cases, nutrient loading due to prolonged wastewater contamination may be great enough to convert a previously unproductive or moderately productive body of water into a very productive, highly *EUTROPHIC*[24] lake. Examples of lakes which have experienced water quality deterioration due to nutrient loading from wastewater are numerous.

Microbiological contamination of a lake or reservoir by wastewater may pose a hazard not only to the domestic water supply but also to persons using the reservoir for recreational purposes such as swimming and water skiing. Diseases caused by protozoans, bacteria and viruses may all result if the microbiological contamination is severe. While conventional water treatment practices do provide protection from microbiological contamination to domestic consumers, the source of supply should still be protected. Some states have regulations relating to the maximum allowable *COLIFORM*[25] bacteria content in domestic water supply reservoirs.

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[24] *Eutrophic (you-TRO-fick). Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.*

[25] *Coliform (COAL-i-form). A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm-blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic (disease-causing) organisms.*

The major source of wastewater contamination in domestic water supply reservoirs is usually wastewater disposal systems such as septic-tank leaching systems. There are two major methods by which contamination from septic-tank systems can be controlled. The first and most dependable solution is to replace all septic-tank leaching systems with well designed sewer systems which collect all wastewater and transport it to centralized treatment facilities. Wastewater treatment facilities should be located outside of the reservoir watershed or at least located so that the treatment plant effluent does not enter the domestic water supply. Unless very expensive nutrient removal treatment processes are used, the nutrient loading in a reservoir from a treatment plant effluent may have a significant impact on algae productivity.

The second major solution is to adopt ordinances or conditions which regulate the design and installation of septic-tank leaching systems to insure that they function properly and do not contaminate the domestic water supply. Provisions should be made for all systems in the watershed to be brought up to established standards. Periodic inspections should verify that the septic-tank leaching systems continue to function properly.

3.312 *Fertilization*

Fertilization of crops and landscaping with materials containing high concentrations of nitrogen compounds can result in these nutrients being carried away in surface runoff and contributing to productivity in the water supply reservoir if fertilization practices are not controlled. Large quantities of fertilizers containing nitrogen compounds are often used in commercial agricultural production, on golf courses and other park-like areas, and for home lawns, orchards and gardens. Nitrogen compounds in excess of those required for plant growth may be leached downward into the groundwater following irrigation and/or precipitation. In many instances the groundwater eventually ends up in the surface water supply reservoir through underflow or surface runoff after it is pumped and used for irrigation. Phosphate-base fertilizers usually do not present the problems that nitrogen fertilizers do because of the soil binding characteristics of phosphate compounds. Once phosphate compounds have entered the soil, they tend to remain there unless taken up by plants. Fertilization practices can be partially controlled by prohibiting use of fertilizers on nonessential crops, but are best controlled through long term public education programs. People who need to use large quantities of fertilizers can be properly trained to apply only enough for adequate plant growth and to apply fertilizers at times when there is minimal chance of excess fertilizer being washed into the water supply. In some major agricultural areas, it is becoming common practice to have a leaf analysis done on crop plants to determine fertilizer needs and application rates. This practice not only protects the water supply from over-fertilization; it is good business practice for the farmer.

3.313 *Industrial Discharges*

Industrial discharges are usually best monitored and controlled by the discharger and a regulatory agency other than the local agency which manages and operates the water supply. In most areas, this responsibility falls under the regulation of a state water pollution control agency. Local water supply agencies can work closely with the pollution control agency in identifying sources of industrial discharges and regulating them so that pollution problems are minimized. Water pollution control programs have been established in each state and are administered under Federal legislation which sets controls on industrial discharges.

NO PANNING
NO BURROS IN WATER

If mining occurs within the watershed and materials mined present a hazard to the water supply, strict regulations should be adopted to prevent water supply contamination. Erosion from mine tailings and exposed areas should be strictly controlled. Recent investigations have shown very high counts of asbestos fibers in portions of some water supplies. A major source of these asbestos fibers is abandoned mining areas through which surface runoff drains. While no state or Federal limits have yet been set on maximum allowable asbestos fiber concentrations in domestic water supplies, there is still serious concern about links between asbestos and some types of cancer.

Oil and gas exploration and drilling must also be regulated so that major contamination of the water supply does not occur. Every agency which operates a surface water supply should prepare and have available an emergency contingency plan which can be implemented immediately if a major spill of hazardous material occurs. County and state health departments, the Federal Environmental Protection Agency, and state pollution control agencies may provide assistance in preparing and implementing hazardous-spill emergency plans.

3.314 *Soil Grading and Farming Practices*

Some watersheds contain soils which, when eroded, may significantly contribute to turbidity in the surface water supply reservoir. Under these conditions it may be necessary to control soil grading and farming practices in sensitive areas. Of particular concern are soils which contain colloidal clays and similar particles which do not settle out in a reasonable period of time within the reservoir. Soil grading and farming practices can be controlled through regulations and ordinances. The major thrust of these rules would not be to prohibit soil disturbances (such as those that occur when farming, logging or constructing housing subdivisions and industrial parks), but to limit disturbances to those times of the year when danger of erosion from surface runoff is at a minimum. Ordinances can also be used to limit the length of time that soil is left exposed and to specify methods of replanting and replacing ground cover.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 86.

3.3D What should be the primary purpose of a watershed management program?

3.3E What problems can be caused in reservoirs from raw wastewater contamination?

3.3F How can problems caused by fertilizers be controlled?

3.3G How can the adverse impacts of soil disturbances from farming, logging and construction be minimized?

3.315 Livestock Grazing

Grazing of livestock can be an invaluable tool for controlling vegetative growth and the potential for wildfire in certain watersheds. However, grazing can also contribute to significant deterioration in water quality within surface water supply reservoirs. Overgrazing can expose soils and lead to increased erosion and turbidity problems. Also nutrients concentrated in cattle manure may be washed into the reservoir during periods of high runoff and cause *EUTROPHICATION.*[26] In addition, accumulations of manure may contribute to microbiological contamination of the domestic water reservoir during major runoff periods. Some of the diseases contracted by humans are carried by animals. In most watersheds, animal grazing can be held within acceptable limits through the implementation of controls and regulations. Grazing can be eliminated or controlled for a limited period of time prior to and during periods of high runoff when fresh manure accumulations would create the greatest hazard to the water supply.

3.316 Pesticides and Herbicides

Unregulated general use of pesticides and herbicides can cause serious problems of contamination in domestic water supply reservoirs. This problem has been minimized on a national level through Federal and local regulations. The Federal government monitors and regulates the use of pesticides and herbicides on watershed lands which it owns or controls. Certain materials are prohibited from use on these lands, some are restricted in their application, and some are approved for general use. All uses are reported on at least an annual basis. In some areas, agricultural commissioners regulate the use of pesticides and herbicides and will usually cooperate with local agencies in setting up controls for specific problem areas such as watersheds. Operators should be notified when pesticides and herbicides are being applied that may pose a threat to the water supply.

3.317 Wildfires

Wildfires in certain watersheds can create more problems for a domestic water supply reservoir than any other source of contamination or pollution. During the runoff period following the fire, large amounts of debris, nutrients, silt and other pollutants may enter the reservoir. Turbidity will usually increase tremendously and will have an adverse effect on water treatment plants. Depending on individual situations and the extent of burning within the watershed, water quality may be degraded (reduced) for a relatively short period of time or for up to several years or more. Reservoir storage space lost to debris and silt accumulations may never be recovered without expensive silt removal.

Fire prevention and control programs are an absolute must in watersheds where major fire hazards exist. Public information programs can often be helpful in preventing fires from occurring. Federal and local fire control agencies can often cooperate in firebreak, vegetation control and other fire control programs. Controlled burning may be a valuable tool in many areas. One fire control measure that is being researched and developed in the western United States is the conversion of chapparal and brushlands to grasslands. This conversion greatly reduces the amount of fuel available to burn. In some instances, the total available water supply can be increased because of increased runoff and reduced *EVAPOTRANSPIRATION*[27] from the grasses.

3.318 Control of Land Use

Most of the Lake Casitas watershed in California lies within a National Forest and presents little hazard to the water quality of the lake except, from wildfires, and those mining, and oil and gas operations permitted. When it was demonstrated that mining operations could significantly reduce the water quality, the Secretary of Interior withdrew permission to mine any U.S. Forest lands within the watershed. The hazards from mining operations can be greatly reduced through such efforts of local, state and Federal agencies.

Approximately 3,000 acres of the Casitas watershed around the Lake was privately owned and considered prime land for subdivision and other types of development in 1972. Studies indicated that any major development would increase the nutrient loading of the lake and lead to serious deterioration of water quality. Because Lake Casitas is located near the Los Angeles Metropolitan Area, it was anticipated that development would occur within a few years. As a result of the studies and much effort on the part of local citizens and governmental agencies and representatives, the U.S. Congress approved funds to buy the privately owned lands and preserve them as open space. A local ordinance was passed which limits public use of the open space lands. Residents in the watershed area who wished to remain were granted 25-year or life estates. The remaining residents must comply with conditions of an agreement controlling activities which would significantly deteriorate water quality. In the case of Lake Casitas, watershed management has proven to be a major factor in the overall program to control and maintain water quality within the lake. This sort of control would not have been politically or economically feasible until one single agency held title to all portions of the watershed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 86.

3.3H How can the use of pesticides and herbicides be controlled in a watershed?

3.3I What problems can be created as a result of a wildfire?

3.3J Under what conditions should an agency consider acquiring title to land in a watershed?

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[26] *Eutrophication (you-TRO-fi-KAY-shun). The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.*

[27] *Evapotranspiration (ee-VAP-o-TRANS-purr-A-shun). The process by which water vapor passes into the atmosphere from living plants.*

3.32 Algae Control By Chemical Methods

3.320 Purpose of Chemical Methods

Chemical control of both planktonic (free-floating) and attached aquatic growths (periphyton) in domestic water supply reservoirs is primarily used to prevent or control taste and odor problems resulting from algal blooms. Many of these algae control programs, however, are expensive and only minimally effective. In some cases it may be much more feasible and economical to limit nutrient availability (and thus prevent major algal blooms) than to correct the problems these blooms cause by the application of chemicals.

A second major purpose of controlling algal blooms by chemical means is to reduce the overall biological productivity. This will reduce the rate of oxygen depletion in the lower parts of the lake. Chemical control programs must be carried out in such a manner that the algal bloom is prevented from becoming intense if the rate of oxygen depletion following die-off is to be reduced. The rate of oxygen depletion in the deeper waters will probably be increased if the bloom is allowed to become intense before chemicals are applied. If algal populations are high when chemical control is started, a large die-off may occur over a very short period of time. This will produce a rapid decomposition of the algal bodies which may cause depletion of dissolved oxygen as well as an increase in tastes and odors. Fish die-offs could result from dead algal bodies clogging their gills or from low dissolved oxygen levels.

A third reason for using chemicals for control of algae is to maintain acceptable aesthetic conditions in the lake or reservoir. Unsightly algal scums, odors, and lack of water clarity may all be controlled by proper application of chemicals for algae control.

3.321 Chemicals Available

There are very few chemicals which can be economically used for controlling algal growths in domestic water supply lakes and reservoirs. Extreme caution must be exercised in selecting chemicals. Many of the most effective materials are not approved for use in domestic waters due to potential hazards for the health of people, fish, and crops. State and/or local health agencies should be consulted before any chemical algal control program is started. Some states or local areas may require permits from, or consultation with, agencies such as the Department of Fish and Game and Department of Agriculture.

Copper sulfate pentahydrate ($CuSO_4 \cdot 5\ H_2O$) or "bluestone," either by itself or in conjunction with certain other chemicals, is the only algicide in common use in domestic water reservoirs at the present time. (Chlorine, used as a bactericide or oxidizing agent, may also produce the effects of an algicide.) Copper sulfate is toxic to many species of algae at relatively low concentrations. Copper sulfate does not present a health hazard to either the workers applying it or to domestic water users if proper application and safety procedures are followed. However, copper sulfate may be a hazard to trout at levels below those necessary to control some algae. Copper sulfate remains relatively inexpensive when compared with other chemicals.

Research by the Metropolitan Water District of Southern California and others, carried out in conjunction with the U.S. Environmental Protection Agency, has pinpointed one major area of concern when copper compounds are regularly added to the water supply source. Water which contains even very low concentrations of copper has been found to cause significant corrosion problems in water distribution systems, particularly those with galvanized piping. The problem appears to be most severe in newer systems where no buildup of calcium or other compounds (which serve to protect the inside of the pipe) has occurred. This problem is more severe in systems supplied with highly mineralized water. Copper residuals in water entering the distribution system must be monitored closely following copper sulfate treatments in order to compile a record of copper concentrations for future reference.

QUESTIONS

Write the answers to these questions in a notebook and then compare your answers with those on page 86.

3.3K Why are chemicals used in domestic water supply reservoirs to prevent or control attached and floating aquatic growths?

3.3L What chemical other than copper sulfate ($CuSO_4 \cdot 5\ H_2O$) may be used as an algicide?

3.322 Chemical Doses

Alkalinity, suspended matter, and water temperature are the three major water quality indicators that affect the efficiency of using copper sulfate as an algicide. Alkalinity of the water is the principal factor that reduces the effectiveness of copper sulfate. In alkaline waters, the copper ions react with bicarbonate and carbonate ions to form insoluble complexes (joined together) that precipitate from solution and reduce the amount of biologically active copper. Once the copper is removed from the ionized form, it is no longer effective as an algicide. Bartsch[28] emphasizes that the copper sulfate dosage should be dependent upon the alkalinity of the water and states that this combination has resulted in successful treatment in various lakes in the midwestern United States. If the *METHYL ORANGE ALKALINITY*[29] of the water is less than 50 mg/*L*, the copper sulfate is effective at the rate of 0.9 pounds of copper sulfate per acre-foot (volume of water) (0.00033 kg/cu m or 0.33 mg/*L*). If the methyl orange alkalinity is greater than 50 mg/*L* the rate should be 5.4 pounds of copper sulfate per acre (surface area of water) (6.06 kg/ha or 0.000605 kg/sq m). In waters with a high alkalinity, the dosage is not dependent upon depth since precipitation of copper would make it ineffective very far below the surface (copper crystals do not dissolve as they fall through the water).

Experience by various researchers and agencies confirms Bartsch's findings that, in most cases, copper sulfate is fully effective as an algicide when the alkalinity is 0 to 50 mg/*L*. These experiences further reveal that at alkalinity concentrations ranging from 50 to 150 mg/*L*, copper sulfate dosages must be increased as the alkalinity increases. When the alkalinity exceeds 150 mg/*L*, the use of copper sulfate by itself as an algicide would not normally be recommended because of its very low effectiveness.

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[28] *Bartsch, A.F., PRACTICAL METHODS FOR CONTROL OF ALGAE AND WATER WEEDS, Public Health Reports, 69:749-757, 1954.*

[29] *Methyl Orange Alkalinity. A measure of the total alkalinity in a water sample. The alkalinity is measured by the amount of standard sulfuric acid required to lower the pH of the water to a pH level of 4.5, as indicated by the change in color of methyl orange from orange to pink. Methyl orange alkalinity is expressed as milligrams per liter equivalent calcium carbonate.*

pH of the water is important for two reasons. The effectiveness of copper sulfate as an algicide depends on the pH. Also the pH level influences the precipitation of copper whose presence is essential to control algae.

Suspended matter in the reservoir or lake being treated with copper sulfate can reduce the effectiveness of copper as an algicide. Such suspended matter provides sites or masses other than algae bodies where the copper is *ADSORBED.*[30] Organic material, both living and dead, adsorbs the copper. Suspended inorganic material, both living and dead, adsorbs the copper. Suspended inorganic sediment is also a significant factor influencing the loss of copper available to kill the algae.

Water temperature plays a major role in how well the copper sulfate kills the algae. When the water temperature drops to the 50°F (10°C) level, algae do not respond to treament as they do at higher temperatures. Higher rates of copper sulfate application will generally be required when water temperature drops below 50°F (10°C). In many reservoirs, major blooms of algae do not occur in colder waters with temperatures below 50°F (10°C). In the majority of cases, the problem blooms take place after surface water temperatures have warmed during spring and summer months.

The amount of copper sulfate required for effective control of algae is also influenced by the species to be treated. Not all algae are alike in their reaction to copper sulfate. Several tiny planktonic green algae, some of the green flagellates, and filamentous blue-green algae are somewhat resistant to the toxic effects of copper sulfate. Most diatoms are quite susceptible to treatment, though they often bloom in large numbers following copper sulfate treatment for other algae. Many of the major taste- and odor-producing, and filter-clogging algae are controlled effectively with low rates of application.

In summary, the following factors influence the concentration of copper sulfate needed for effective control of any particular algal bloom: (1) species of algae, (2) amount of algae, (3) alkalinity of the water, (4) pH of the water, (5) water temperature, and (6) quantity of suspended matter and organic material in the water.

The maximum rate of application of copper sulfate in domestic water supply sources is currently influenced by regulations limiting the concentration of copper in *POTABLE WATER*[31]. The Environmental Protection Agency (EPA) has established a maximum allowable concentration of one mg/*L* copper in potable water after treatment. Another important consideration is the tolerance of fish and other aquatic organisms to copper. Copper sulfate products are currently registered through the EPA for use in controlling algae. To comply with these Federal requirements, copper sulfate products properly labeled for the intended use must be selected.

Investigation and field experiments by various individuals and agencies have indicated that effective use of copper sulfate as an algicide can be accomplished in highly alkaline water when the copper sulfate is combined with *ALIPHATIC HYDROXY ACIDS*[32]. These acids have proven effective for delaying the chemical reaction of copper with the bicarbonate and carbonate ions of the water and thereby preventing the immediate precipitation of copper in alkaline waters. The most commonly used of these acids is citric acid which is normally mixed with the copper sulfate in a ratio of approximately two parts copper sulfate to one part citric acid regardless of the alkalinity. The Casitas Municipal Water District has used a copper sulfate plus citric acid mixture with satisfactory results for over ten years in Lake Casitas. Lake Casitas water has an alkalinity of approximately 150 mg/*L*. Several commercially prepared *CHELATED*[33] copper compounds for use in alkaline waters are presently available and may prove to be economical for use in many situations.

QUESTIONS

Write the answers to these questions in a notebook and then compare your answers with those on page 86.

3.3M Why is the dose of copper sulfate based on either surface area or volume of reservoir?

3.3N How does suspended particulate matter in a reservoir reduce the effectiveness of copper as an algicide?

3.3O What is the major factor limiting the maximum rate of application of copper sulfate in the sources of a domestic water supply?

3.323 Methods of Chemical Application

Methods of using copper sulfate compounds range from very simple to very elaborate depending upon the size of the reservoir to be treated, frequency of treatment, and rates of application. Depending on the method of application, copper sulfate may be purchased in dry form with crystal size ranging from snowflake to large diamond size of up to one inch (25 mm) or more in diameter. Some of the most commonly used methods for applying copper sulfate compounds are summarized in the following paragraphs.

1. The simplest method, and one which may be most applicable in very small lakes and reservoirs, is to drag burlap bags containing the copper material through the water using a boat. The reservoir surface is normally crisscrossed in a zigzag fashion so as to cover all of the

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[30] *Adsorbed (add-SORB-ed). The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.*

[31] *Potable Water (POE-tuh-bull). Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered safe for drinking.*

[32] *Aliphatic Hydroxy Acids (AL-uh-FAT-ick). Organic acids with carbon atoms arranged in branched or unbranched open chains rather than in rings.*

[33] *Chelated (key-LATE-ed). A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of the metals (copper).*

water surface. Mixing of the material within the water is accomplished by wind, diffusion and gravity. Boat speed, number of bags used and the size of the crystals can all be regulated to produce the desired rate of application.

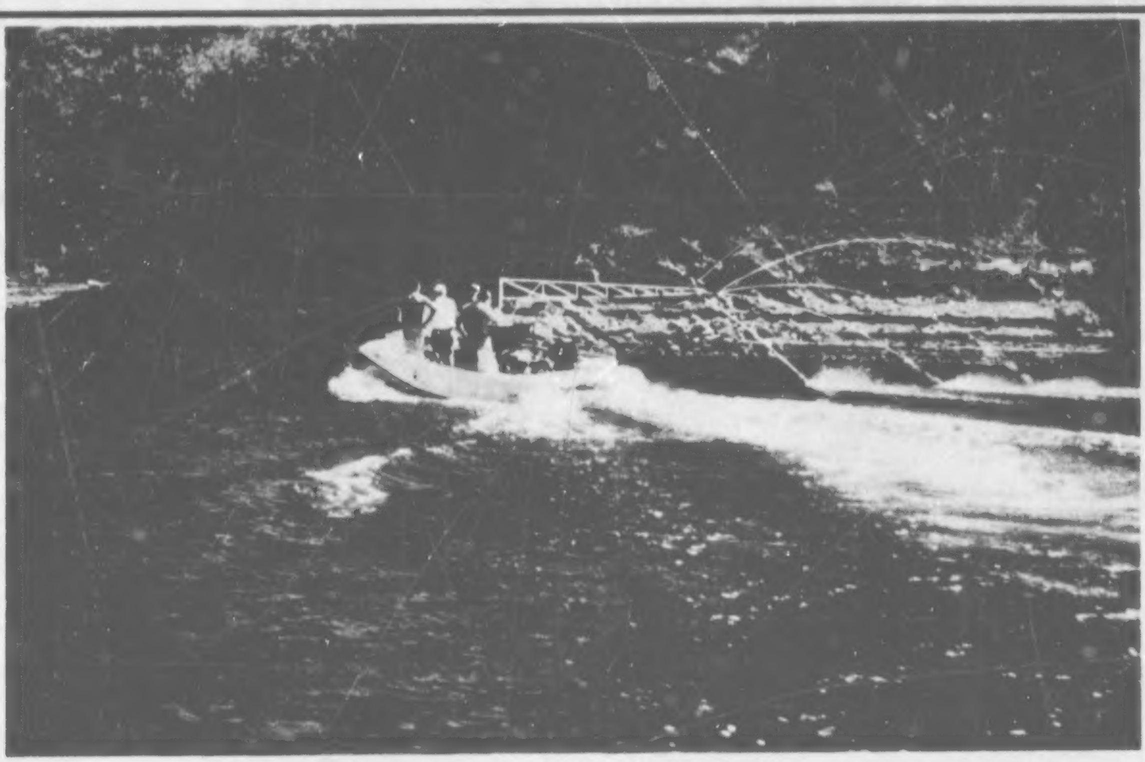
2. Dry copper sulfate crystals may be dumped into a hopper mounted on a boat in such a way that they can be fed into a broadcaster (such as the type used for spreading grass seed) which distributes them onto the lake surface. If the entire surface area of the reservoir is to be treated, the material can be applied in criss-cross pattern. Holes can be drilled or cut in the bottom of the hopper to control how much material is released onto the broadcaster. Boat speed, width of area covered by broadcaster, and rate of copper sulfate fed through the holes can be calculated and adjusted to produce the desired application rate.

3. Perhaps the most efficient and safest method of applying copper sulfate is to mix it into solution and spray it onto the reservoir surface (Figure 3.8) or pump it into the reservoir through a length of pipe (preferably plastic) which contains a number of holes. The pipe may be 15 to 20 feet (4.5 to 6 m) long with the holes about two feet (0.5 m) apart. The pipe can be mounted behind the boat below the surface of the water, and perpendicular to the direction of travel. The primary advantage of this submerged application instead of spraying is that the application of the solution is unaffected by wind. The disadvantages of the submerged application are that it is difficult to tell when the holes are plugged and the delivery system may be damaged or caught in submerged trees or brush, especially in shallow water. Figure 3.9 shows the spreading method of applying copper sulfate from a boat.

Mixing algicide chemicals into solution is a good method when citric acid is combined with the copper sulfate to prevent the precipitation of copper in alkaline waters. Copper sulfate in snowflake-size crystals works best for this method of application. Copper sulfate is commonly supplied in 80-pound (36 kg) bags which are easy to move and store. Citric acid, which is supplied in granular form in bags, is also easy to use.

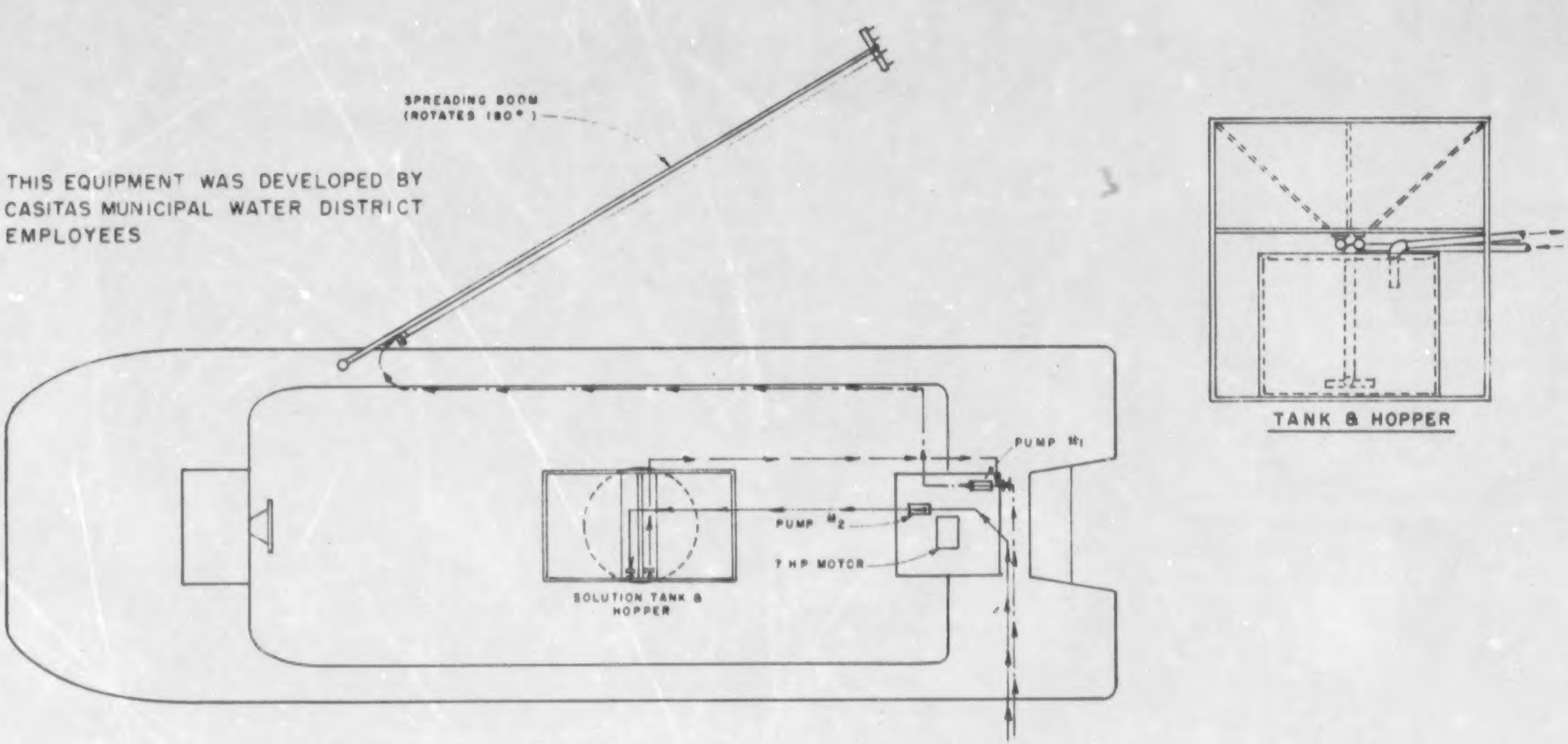
To get the materials into solution, they are loaded on the boat or barge in bags and fed into a hopper designed so that different-sized holes can be fitted into the bottom outlet. The various hole sizes allow adjustment of the rate at which material is released from the hopper. If two chemicals are to be mixed, a divided hopper can be used with different sized holes so that the feed rate of each chemical can be adjusted independently. If the hopper is made of steel, it can be coated with an epoxy material in order to limit corrosion.

The materials are fed from the hopper into a corrosion-resistant tank where they are mixed into solution using water pumped into the tank from the lake or reservoir. Once



Note spray from chemical solution hitting water
on right of boat.

Fig. 3.8 Application of copper sulfate and citric acid


SPREADING BOOM (ROTATES 180°)
SOLUTION TANK & HOPPER
PUMP #1
PUMP #2
7 HP MOTOR
TANK & HOPPER

THIS EQUIPMENT WAS DEVELOPED BY CASITAS MUNICIPAL WATER DISTRICT EMPLOYEES

MOTOR - 7 HP WISCONSIN WITH CLUTCH ASSEMBLY
PUMP #1 - 1¼" MODEL 6400 JABSCO
PUMP #2 - 1" MODEL 777 JABSCO
NOZZLE - 4 1/8" PIPE
BOAT - 21'-4" BOSTON WHALER (1972)
MOTOR - 85 HP OUTBOARD

Fig. 3.9 Copper sulfate spreading equipment

in solution, the materials are applied to the lake or reservoir by pumping through the spray nozzles or thorugh submerged outlets. By proper regulation of flow through the pumps, the solution level within the tank can be regulated. The desired rate of application of chemicals can be obtained by considering the speed of the boat, the rate at which material is fed from the hopper and pumped into the lake, and the area covered by the spray apparatus or submerged outlet system.

When computing the amount of copper sulfate required to produce the required dosage, it must be remembered that copper sulfate penta-hydrate contains approximately 25 percent copper. For a one mg/*L* dose of copper to be obtained in one million gallons of water, 33.4 pounds of copper sulfate should be added.

$$\frac{(8.34\text{ lbs copper/million gallons})}{25\%\text{ available copper}} \times 100\% = \frac{33.4\text{ lbs copper sulfate}}{\text{million gal water}}$$

Note that 8.34 pounds of a substance in a million gallons of water is equal to one mg/*L*.) By knowing the quantity of water to be treated in millions of gallons, and the desired dose, it is relatively simple to compute the amount of copper sulfate required per application.

FORMULAS

In order to calculate the dose of copper sulfate to be applied to a reservoir we need information regarding (1) the reservoir and (2) the desired dosage in terms of either the reservoir surface area or volume.

1. Reservoir information is usually available in terms of surface area and volume on the basis of water surface level or elevation. Sometimes these are available in terms of depth vs surface area or depth vs volume curves (Figure 3.10). If these curves are available, simply observe the depth of water or surface elevation and obtain the reservoir surface area and volume from the curves. The information used to plot these curves may be available in a table also.

If the reservoir volume is given in acre-feet, you may have to convert this number to a volume in million gallons.

$$\text{Volume, Gallons} = (\text{Volume, ac-ft})(43{,}560\text{ sq ft/ac})(7.48\text{ gal/cu ft})$$

The reservoir volume in acre-foot is multiplied by 43,560 square feet per acre to give us a volume in cubic feet. We multiply this number by 7.48 gallons per cubic foot to obtain a volume in gallons.

Frequently we want the volume in millions of gallons, instead of gallons.

$$\begin{aligned}\text{Volume, Million Gallons} &= \frac{(\text{Volume, Gallons})\ (1\text{ Million})}{1{,}000{,}000}\\ &= \frac{(5{,}000{,}000\text{ Gallons})\ (1\text{ Million})}{1{,}000{,}000}\\ &= 5.0\text{ Million Gallons}\end{aligned}$$

When we multiply a volume in gallons by (1 Million/1,000,000) we are only changing the units. In the above example we changed a volume of 5,000,000 gallons to 5 million gallons, which are both the same.

2. The copper sulfate required in pounds may be determined on the basis of reservoir volume or reservoir surface area. Another important factor is whether the desired dose is given in terms of a concentration of *COPPER* in milligrams of copper per liter of water or as an application of *COPPER SULFATE* in pounds of copper sulfate per acre of water surface area.

If the desired dose is given as mg/*L* of copper, calculate amount of copper needed in pounds as follows:

$$\text{Copper, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal}).$$

We can check these units by knowing that one liter of water weighs one kilogram. Also one kilogram is equal to 1,000 grams and one gram equals 1,000 milligrams. Therefore one liter weighs one million milligrams. One mg/*L* is sometimes referred to as one part per million (ppm) or one milligram per million milligrams or one pound per million pounds.

$$\begin{aligned}\text{Copper, lbs} &= \frac{(\text{Volume M Gal})\ (\text{Dose, mg})\ (8.34\text{ lbs/gal})}{(1\text{ Million mg})}\\ &= \frac{(\text{Volume, M Gal})\ (\text{Dose, lbs})\ (8.34\text{ lbs/gal})}{(1\text{ Million lbs})}\\ &= \text{pounds of copper}\end{aligned}$$

When we add copper sulfate to water, 25 percent of the copper sulfate is copper or for every four pounds of copper sulfate we add to the reservoir, we are actually adding one pound of copper.

$$\text{Copper Sulfate, lbs} = \frac{(\text{Copper, lbs})\ (100\%)}{25\%}$$

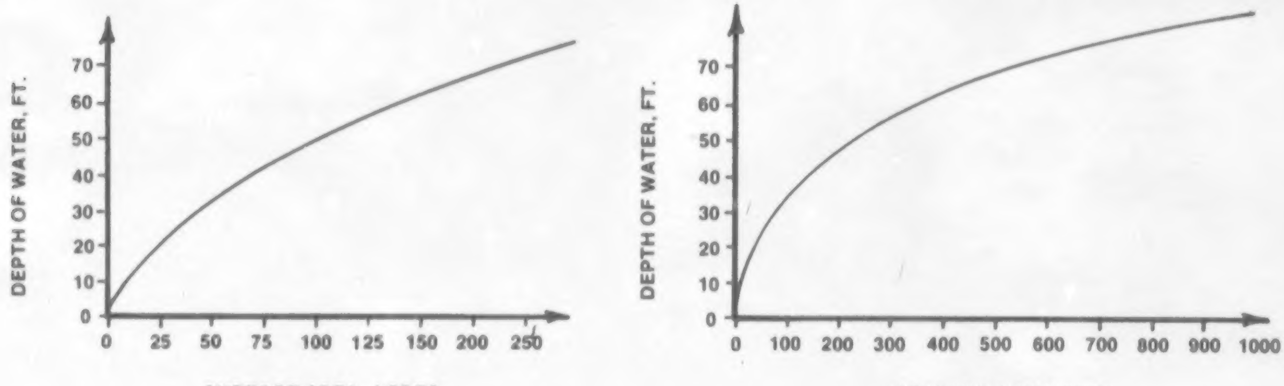


Fig. 3.10 Depth vs surface area and volume curves

By combining these two formulas, we obtain the formula for calculating the pounds of copper sulfate needed when we have the reservoir volume in million gallons and the copper dose in mg/*L*.

$$\text{Copper Sulfate, lbs} = \frac{(\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})(100\%)}{25\%}$$

If the copper sulfate dose is given in pounds of copper sulfate per acre of water surface, use the following formula:

$$\text{Copper Sulfate, lbs} = (\text{Surface Area, ac})(\text{Dose, lbs/ac})$$

If the alkalinity of the water is greater than 150 mg/*L*, add one pound of citric acid for every two pounds of copper sulfate.

$$\text{Citric Acid, lbs} = \frac{(\text{Copper Sulfate, lbs})(1\text{ lb Citric Acid})}{2\text{ lbs Copper Sulfate}}$$

NOTE: Actual desired copper concentrations in mg/*L*, copper sulfate doses in pounds per acre, and citric acid doses may vary with each reservoir. Only by monitoring doses and by observing and analyzing results can operators determine the most cost-effective copper sulfate program for their reservoirs.

EXAMPLE 1

A small storage reservoir has a surface area of five acres and contains 80 acre-feet of water. How many pounds of copper sulfate pentahydrate are needed for 0.5 mg/*L* dose of copper? Copper sulfate pentahydrate contains 25 percent copper. Assume the alkalinity is 40 mg/*L*.

Known		Unknown
Surface Area, ac	= 5 ac	Copper Sulfate lbs
Volume, ac-ft	= 80 ac-ft	
Copper Dose, mg/*L*	= 0.5 mg/*L*	
Copper, %	= 25%	
Alkalinity, mg/*L*	= 40 mg/*L*	

Basic Formula

$$\text{Copper Sulfate, lbs} = \frac{(\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})(100\%)}{(\text{Copper, }\%)}$$

1. Convert acre feet to million gallons.

$$\begin{aligned}\text{Volume, M Gal} &= (\text{Volume, ac-ft})(43{,}560\text{ sq ft/ac})(7.48\text{ gal/cu ft})\\ &= (80\text{ ac-ft})(43{,}560\text{ sq ft/ac})(7.48\text{ gal/cu ft})\\ &= 26{,}066{,}304\text{ gal}\ \frac{(1\text{ Million})}{(1{,}000{,}000)}\\ &= 26.07\text{ Million Gallons}\end{aligned}$$

2. Calculate the pounds of copper sulfate needed.

$$\begin{aligned}\text{Copper Sulfate, lbs} &= \frac{(\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})(100\%)}{(\text{Copper, }\%)}\\ &= \frac{(26.07\text{ MG})(0.5\text{ mg}/L)(8.34\text{ lbs/gal})(100\%)}{25\%}\\ &= 435\text{ lbs copper sulfate}\end{aligned}$$

NOTE: In large reservoirs the total volume of water may not need to be treated. From experience the operator may decide to treat only the top 20 feet (6 meters) or down to the thermocline.

EXAMPLE 2

How many pounds of copper sulfate pentahydrate would be required for the reservoir in EXAMPLE 1 if the alkalinity of the water was 175 mg/*L*? Since the alkalinity is greater than 150 mg/*L*, the recommended copper dose is 5.4 lbs of copper sulfate per acre of water surface area.

Known		Unknown
Surface Area, ac	= 5 ac	Copper Sulfate, lbs
Volume, ac-ft	= 80 ac-ft	
Copper Sulfate Dose, lbs/ac	= 5.4 lbs/ac	
Alkalinity, mg/*L*	= 175 mg/*L*	

Calculate the pounds of copper sulfate pentahydrate needed.

$$\begin{aligned}\text{Copper Sulfate, lbs} &= (\text{Surface Area, ac})(\text{Dose, lbs/ac})\\ &= (5\text{ ac})(5.4\text{ lbs/ac})\\ &= 27\text{ lbs copper sulfate}\end{aligned}$$

NOTE: If the alkalinity is greater than 150 mg/*L*, citric acid may have to be mixed with the copper sulfate and the copper sulfate may have to be added to the reservoir more frequently. When citric acid is added, copper will remain in solution and the dosage should be based on volume of water, not surface area. The dosage of citric acid is usually one pound of citric acid for every two pounds of copper sulfate, regardless of how much the alkalinity is over 150 mg/*L*.

EXAMPLE 3

How many pounds of citric acid would be required for the reservoir in EXAMPLE 2 if the recommended dose of citric acid is one pound of citric acid for every two pounds of copper sulfate applied? Copper sulfate dose in EXAMPLE 2 was 27 pounds.

Known		Unknown
Copper Sulfate, lbs	= 27 lbs	Citric Acid, lbs
Citric Acid Dose	$= \dfrac{1\text{ lb Acid}}{2\text{ lbs Copper Sulfate}}$	

Calculate the pounds of citric acid needed.

$$\begin{aligned}\text{Citric Acid, lbs} &= \frac{(\text{Copper Sulfate, lbs})(1\text{ lb Citric Acid})}{(2\text{ lbs Copper Sulfate})}\\ &= \frac{(27\text{ lbs Copper Sulfate})(1\text{ lb Citric Acid})}{2\text{ lbs Copper Sulfate}}\\ &= 13.5\text{ lbs Citric Acid}\end{aligned}$$

When applying copper sulfate or any other chemical, you will have to experiment to find the best dosage for your situation. Whether your doses are based on the entire reservoir volume, or only on the surface area, the amount of chemical required will vary with location, time of year and water quality. Another important variable is the frequency of application of chemicals. To determine the best dosage and frequency of dosing, you will have to develop and analyze the results of a reservoir monitoring program.

3.324 Monitoring

In reservoirs where algae are a potential problem, the operator must have a monitoring program capable of anticipating a possible algal bloom. When the data reveal that a bloom is likely, the operator must take the necessary treatment action to prevent the bloom. After a bloom occurs it is more difficult, if not almost impossible, to control the bloom and correct the bad effects on water quality.

Whenever a chemical algae control program is started, monitoring should be carried out before, during, and after use of chemicals. Before, and for several days after the chemical application, data on type of algae, amount of algae and where they are located should be collected in order to evaluate the effectiveness of treatment at the dosage applied. Careful evaluation must be made to determine if algae die-offs actually occur as a result of the chemical application or if they simply died off due to natural circumstances. This can best be accomplished by monitoring bloom/die-off cycles under natural conditions when no chemical treatment is carried out. Careful monitoring of algicide residual concentrations should be practiced during and following treatment in order to determine if the desired dose is obtained and the extent of the algicide distribution. For example, if the water body is to be treated to a depth of 15 feet (4.5 m), it may be necessary to adjust application methods in order to obtain an effective residual to this depth. Accurate data should be kept on the actual algicide concentration (copper for example) in the reservoir or water supply in case legal questions regarding causes of fish die-off or system corrosion arise.

3.325 Recordkeeping

Full and accurate recordkeeping should be an important part of any chemical algae control program. These records are valuable when evaluating current and historical treatment programs, for designing new or revising existing programs, and for showing compliance with Federal, state or local regulations.

3.326 Safety

Employee and public safety is an important concern in chemical algae control programs. Proper procedures for handling and applying chemicals must be strictly followed. Besides following precautions listed by the chemical manufacturer, anyone applying chemicals should refer to the regulations of Federal and state agencies (such as their state OSHA program). Particular caution must be exercised when applying copper sulfate in dry form to protect employees and the public from the dust. Special clothing, gloves and breathing apparatus should be required. In some cases, it may be necessary to close the lake or reservoir to public use during periods of chemical application in order to protect the public from dust or spray.

If chemicals are to be applied from a boat, operators must observe water safety procedures. Personal flotation devices must be carried on the boat and, in most cases, must be worn while working. Employee training in water safety and first aid procedures is always a good idea and may be legally required.

3.327 Additional Reading

Several publications contain more information about algae and weed control by chemical methods and should be used as references when planning and implementing algae control programs. Information included in these publications ranges from methods of applying chemicals to estimated copper concentrations required to control specific groups and species of algae. Information from these publications has been used extensively in the preparation of this section on algae control. These references are listed as follows:

1. *ALGAE IN WATER SUPPLIES* — An Illustrated Manual on the Identification, Significance and Control of Algae in Water Supplies by C. Mervin Palmer, U. S. Public Health Service Publication No. 657, reprinted 1962. Available from Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402. Stock Number 55-001-01081-8. Price $4.00.
2. *THE USE OF COPPER SULFATE IN CONTROL OF MICROSCOPIC ORGANISMS*, by Frank E. Hale, Ph.D. Presented by Phelps Dodge Refining Corp., 300 Park Avenue, New York, New York 10022.
3. *INVESTIGATIONS OF COPPER SULFATE FOR AQUATIC WEED CONTROL*. A Water Resources Technical Publication, Research Report No. 27, U. S. Department of Interior, Bureau of Reclamation. For sale by the Bureau of Reclamation, Attention D-922, Engineering and Research Center, P. O. Box 25007, Denver Federal Center, Denver, Colorado 80225. Stock Number 024-003-00101-5. Price 85 cents, minimum order $1.00.
4. *HOW TO IDENTIFY AND CONTROL WATER WEEDS AND ALGAE*. Created and produced by Applied Biochemists, Inc., 5300 West County Line Road, Mequon, Wisconsin 53092. Price $4.95.

QUESTIONS

Write the answers to these questions in a notebook and then compare your answers with those on page 86.

3.3P List three methods of applying copper sulfate compounds to a reservoir.

3.3Q How is the effectiveness of a chemical algae control program evaluated?

3.3R What safety precautions should be taken by a person applying copper sulfate in the dry form?

End of Lesson 1 of 2 Lessons
on
Reservoir Management
and
Intake Structures

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

(Lesson 1 of 2 Lessons)

Please write your answers to these questions in your notebook before continuing with Lesson 2. The purpose of these questions is to indicate to you how well you understand the material in this lesson.

1. What purposes may a reservoir be used for other than as a source for a domestic water supply?
2. What types of public use may be allowed on water supply reservoirs?
3. Algal blooms can cause what types of problems in domestic water supply reservoirs?
4. Under what circumstances are tastes and odors in a domestic water supply most noticeable?
5. How can a water agency meet acceptable trihalomethane levels?
6. Iron and manganese can cause what kinds of water quality problems in drinking water?
7. Why is it difficult to find the best level from which to withdraw acceptable domestic water from a monomictic, productive lake during the summer when thermal stratification exists?
8. Reservoir water quality management programs can control or eliminate what types of water quality problems?
9. How can the recreational values of a reservoir be improved by proper reservoir management?
10. How can water quality problems caused by septic-tank leaching systems by solved?
11. What are the advantages and limitations of grazing livestock on the watershed of a water supply reservoir?
12. Why is copper sulfate used to control algal blooms?
13. How does alkalinity in water reduce the efficiency of using copper sulfate as an algicide?
14. How can the desired rate of copper sulfate application to a reservoir by achieved?

CHAPTER 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

(Lesson 2 of 2 Lessons)

3.33 Reaeration and Artificial Destratification

3.330 Terminology

To help you understand this section, we will first define three important terms.

1. Aeration (air-A-shun). The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.
2. Reaeration (RE-air-A-shun). The introduction of air through forced air diffusers into the lower layers of the reservoir. As the air bubbles form and rise through the water, oxygen from the air dissolves into the water and replenishes the dissolved oxygen. Also the rising bubbles cause the lower waters to rise to the surface where oxygen from the atmosphere is transferred to the water. This is sometimes called surface reaeration.
3. Destratification (de-STRAT-uh-fuh-KAY-shun). The development of vertical mixing within a reservoir to eliminate (either totally or partially) separate layers (of temperature, plant, or animal life) in a lake or reservoir. This vertical mixing can be caused by mechanical means (pumps) or through the use of forced air diffusers which release air into the lower layers of the reservoir.

In this section when we use the term "reaeration-destratification," we are using air to destratify the reservior. A relatively small amount of replenishment of the dissolved oxygen in the water actually occurs. The dissolved oxygen is no where close to saturation as a result of this procedure. Also the reservoir may be only partially destratified as a result of this procedure. The entire reservoir may not be destratified, but mixing will occur between the upper and lower layers of water.

3.331 Purpose of Reaeration-Destratification Programs

The primary purpose of reaeration-destratification programs in domestic water supply reservoirs is usually to eliminate, control, or minimize the negative impacts on domestic water quality which occur during periods of thermal stratification and dissolved oxygen depletion. A secondary purpose may be to increase recreational values of the reservoir through expanded and improved fisheries and improved aesthetic conditions. In reservoirs which freeze over during the winter, reaeration-destratification equipment may be used to reduce winter fish kills in waters which normally become anaerobic, and to prevent portions of the lake or pond from freezing over. Prevention of freezing can be accomplished by circulating water vertically within a lake or reservoir. This practice is particularly helpful in marina areas when open water can be maintained around boat docks and related facilities.

Water quality improvement is obtained by the addition of dissolved oxygen to zones within the lake which would normally become anaerobic during periods of thermal stratification. In reservoirs which have a single outlet gate located at a depth where anaerobic conditions exist during portions of the year, reaeration-destratification systems offer a method of improving water quality for delivery to water treatment-distribution facilities. In reservoirs with multi-level outlets which permit selection of the depth from which water is withdrawn, it is possible to select the depth at which the best water quality exists.

Under certain conditions destratification-reaeration programs may not solve all the problems that they are intended to solve. In large lakes and reservoirs, it is very difficult to design and operate the system so that an adequate amount of oxygen is added to the water at the lowest cost. A monitoring program must be in use prior to and along with reaeration-destratification programs in order to evaluate both positive and negative impacts on water quality.

Researchers and reservoir operators who have used and evaluated reaeration-destratification programs are still debating the impact of these programs on algal blooms. Some investigators have reported significant reductions in the intensity of algal blooms and a shift in the species of algae responsible for the blooms. In some cases taste- and odor-producing blue-green algae have been replaced by certain species of green algae which do not cause taste and odor problems. Other investigators have noted increases in intensity of algal blooms and taste and odor problems following start-up of reaeration-destratification systems.

Reaeration-destratification effects on algal blooms appear to be related to what happens to nutrient conditions within the reservoir as a result of reaeration-destratification. In lakes and reservoirs which are anaerobic on the bottom and stratified, nutrients (particularly phosphate and nitrate compounds) may be released in large quantities from the bottom sediments into the hypolimnion. Following turnover these nutrients are mixed into the upper waters where they are available for promoting algal growth under certain environmental conditions. By eliminating anaerobic zones, reaeration-destratification systems may control or eliminate this release of nutrients from the bottom sediments, thereby reducing algal blooms. In some instances, however, reaeration-destratification systems themselves may cause the nutrients within bottom sediments or deeper portions of the reservoir to be mixed upward into the surface waters. When this happens, nutrients become available to algae, thereby increasing algal blooms during certain periods of the year. The number of reservoirs where algal blooms have been decreased by reaeration-destratification appears to be much larger than reservoirs where algal blooms have been increased.

Reservoir operators should collect enough water quality data (temperature, dissolved oxygen, pH, nutrients, alkalinity, suspended matter, turbidity, *SECCHI DISC*[34] transparency) to make their own analysis of the effects of reaeration-destratification programs upon algal and other environmental conditions.

3.332 Methods of Reaeration

There are two basic methods of maintaining or even increasing dissolved oxygen concentrations within zones of reservoirs which would be partially or fully oxygen-depleted when thermal stratification exists. There are many ways (some much more economical than others) in which each of these methods can be used. The first method accomplishes atmospheric reaeration by either altering or totally eliminating thermal stratification and is commonly referred to as destratification. The second method adds dissolved oxygen directly to the hypolimnion without significantly altering the pattern of thermal stratification and is referred to as hypolimnetic reaeration.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.3S What is the primary purpose of reaeration-destratification programs in domestic water supply reservoirs?

3.3T How can water quality be improved by a reaeration-destratification program?

3.3U List the two basic methods of maintaining or increasing dissolved oxygen concentrations in reservoirs when thermal stratification exists.

3.333 Destratification

Destratification (either total or partial) is accomplished by inducing vertical mixing within the reservoir. This can be done by mechanical means (pumps) or through the use of diffused air which releases air bubbles into the hypolimnion of the reservoir, usually in the deepest portion. Mechanical systems accomplish destratification and mixing either by pumping hypolimnetic waters to the surface or by pumping surface waters downward.

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[34] *Secchi Disc (SECH-key). A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.*

Common practice with diffused air systems using air compressors is to locate them either onshore or on a floating barge or platform as near as possible to the point where the air is to be released into the reservoir. Air is delivered from the compressors into an air supply line which is connected to a system of diffusers. The diffusers release the air near the bottom of the lake or reservoir (Figures 3.11 and 3.12). As the air bubbles rise toward the surface they act like a pump, carrying the colder, more dense water upward. Being more dense, the colder water tends to eventually sink downward, causing vertical circulation. With complete destratification, surface waters are cooled and deeper waters are warmed until an equilibrium is reached and temperatures are nearly equal from top to bottom. One major disadvantage of complete destratification is that deeper waters may become warmer than desired for domestic water and for certain species of fish. However, cooler surface temperatures reduce evaporation losses.

Dissolved oxygen is added to deeper waters as they mix with upper waters and make contact with the atmosphere at the surface. Some oxygen enters the water through transfer from the bubbles as they rise toward the surface. Through proper design and operation, destratification systems can be used to adjust temperatures as well as dissolved oxygen levels.

In any given reservoir, the rate of oxygen depletion within the metalimnion and hypolimnion zones may vary considerably from one year to the next depending upon algal blooms, die-off and other biological factors. During years of heavy runoff, higher nutrient inflow may increase biological productivity and the rate of oxygen depletion. In these high runoff years, it may be necessary to circulate water from the deeper zones through more complete mixing.

3.334 Mechanical or Hydraulic Mixing

Destratification of lakes and reservoirs by mechanical or hydraulic mixing has been practiced and evaluated to a much lesser extent than diffused-air mixing. The hydraulic system pumps water from one level of the reservoir and jets it into another area of different *DENSITY*.[35] The pumped water stream induces circulation and mixing. Several different types of mechanical systems have been designed and used, but few, if any, of these systems have remained in operation to control water quality on a routine basis. With many of these systems, power requirements are very high when compared to similar diffused-air mixing systems, making them less efficient and more costly to operate. Dortch[36] has indicated that hydraulic destratification can be an effective means of mixing and may be more efficient than air for mixing large reservoirs and lakes. Further information on mechanical and hydraulic mixing devices is included in the four publications listed in Section 3.335.

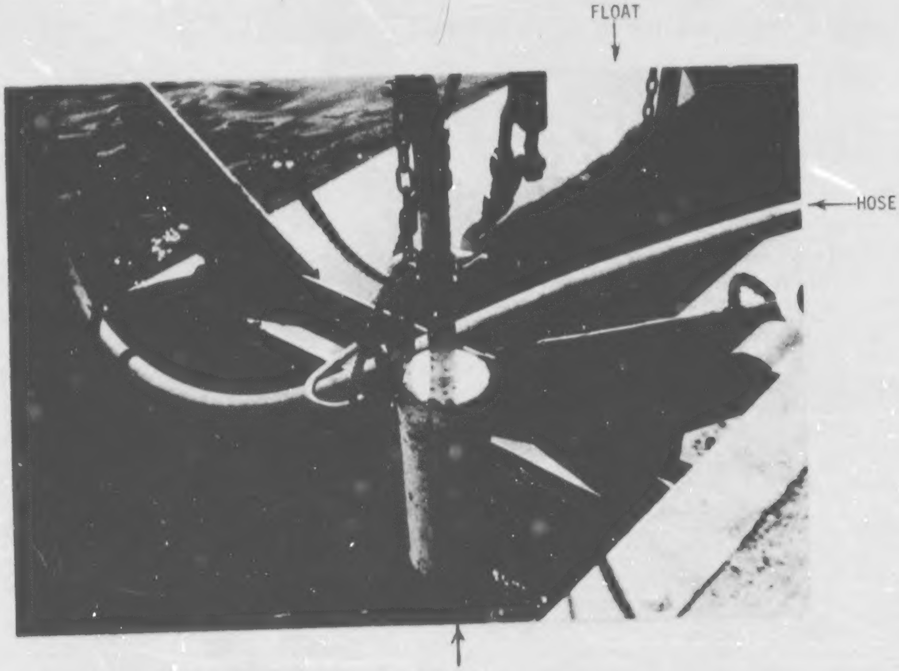

Fig. 3.11 Aeration system showing float, hose and diffuser

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[35] *Density (DEN-sit-tee). A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.*

[36] *Dortch, Mark S. "Method of Total Lake Destratification," published in DESTRATIFICATION OF LAKES AND RESERVOIRS TO IMPROVE WATER QUALITY, Australian Water Resources Council Conference Series No. 2, Canberra.*

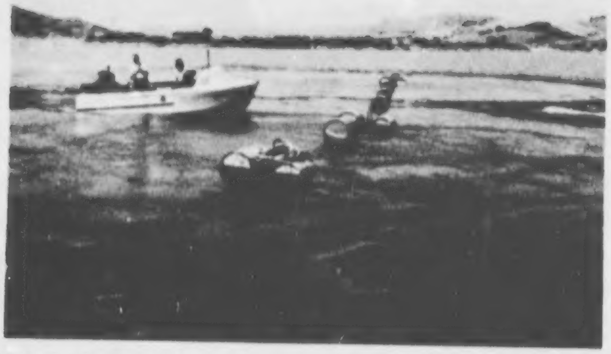


Fig. 3.12 Reaeration-destratification system in operation

Reaeration systems all have one thing in common: they increase the dissolved oxygen content of the hypolimnetic waters while at the same time they maintain thermal stratification. Hypolimnetic reaeration is accomplished by injecting very small air bubbles or pure oxygen into the hypolimnion of a lake or reservoir or by spraying hypolimnetic water into the air and returning it to the hypolimnion. Hypolimnetic aeration has special applications in ice-covered lakes where it may be necessary to control dissolved oxygen depletion and water quality while at the same time preventing open water conditions from occurring.

In some frozen lakes used by the public, diffused air systems may present a safety hazard by creating open water conditions. In lakes which support cold water fisheries, it may be necessary to practice hypolimnetic aeration to maintain suitable water temperatures. Hypolimnetic aerators which use pure oxygen for reaeration are often not economical for use in large domestic water supplies. Information on the design and use of various types of hypolimnetic reaeration devices is available in the four publications listed in Section 3.335.

3.335 Development of Reaeration-Destratification Programs

Publications which contain valuable references and information relative to design, operation, advantages, disadvantages, and economies of reaeration-destratification systems should be closely reviewed before deciding to install a system in a particular reservoir. Here's a list of some of the more helpful publications.

1. *SYMPOSIUM ON REAERATION RESEARCH*, Proceedings — Hydraulics Division Specialty Conference, Gatlinburg, Tennessee, October 28-30, 1975. Sponsored by the Hydraulics Division, American Society of Civil Engineers, 345 East 47th Street, N.Y., N.Y. 10017. Price $20.00.
2. *A GUIDE TO AERATION CIRCULATION TECHNIQUES FOR LAKE MANAGEMENT*. October 1976, TetraTech, Inc., prepared for Corvallis Environmental Research Laboratory, U.S. Environmental Protection Agency, Corvallis, Oregon 97330 (Office of Research and Development).
3. Australian Water Resources Council — Technical Paper No. 46, *EFFECTS ON WATER QUALITY OF ARTIFICIAL AERATION AND DESTRATIFICATION OF TARAGO RESERVOIR*. Available from Australian Government Publishing Service, Canberra, 1979.
4. *DESTRATIFICATION OF LAKES AND RESERVOIRS TO IMPROVE WATER QUALITY*, Proceedings of Joint United States/Australia Seminar and Workshop, Melbourne, Australia, Feb. 19-24, 1979. Department of National Development and Energy, Australian Water Resources Council, Australian Government Publishing Service, Canberra, 1981.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.3V How can destratification be accomplished?

3.3W What factors could cause the rate of dissolved oxygen depletion in a reservoir to vary considerably from one year to the next?

3.34 Managing Frozen Reservoirs by Dick Krueger

In cold climates, impoundment facilities such as open reservoirs and man-made or natural lakes can have ice formations to varying degrees of severity during winter months. To guarantee trouble-free use and operation of these facilities, certain steps should be taken in preparation for cold winters to minimize the harmful effects ice formations have on waterworks operations.

3.340 Physical Effects of Ice Formation

3.3400 Water Level. In anticipation of ice formation on lakes and reservoirs, operators should regulate the water level of the reservoir and maintain an optimum level until the reservoir becomes frozen over. Then the water level should be lowered, sagging the ice cover and reducing the ice pressure on structures and embankments, thus minimizing damages due to ice formation.

3.3401 Lake Level Measurement. In order to manage available water resources efficiently, operators have to balance withdrawal from and inflow to the reservoir and determine a withdrawal rate that will guarantee an uninterrupted minimum water supply to the community for domestic and fire-fighting purposes. This can only be accomplished by continuous monitoring of the water level under the ice.

A float arrangement, though simple and reliable, is impractical when ice formation is encountered. An alternate measuring system should be used, such as a manometer or a bubbler tube. The bubbler tube should be equipped with a heating tape (Pyrotenax Cable) to insure that no ice will form along the bubbler tube pipe.

3.3402 Intake Screens. Inspections of intake screens should be carried out frequently to insure that debris, ice (sheet) buildup or frazzle (granular) ice will not obstruct the water flow. In case ice or frazzle ice is encountered, a portable steam generator with sufficient length of hose should be available to counter any serious buildup.

3.3403 Intakes. If the intake design allows for withdrawal of water from different depths of the lake, the top intakes should be closed during winter months and water should be withdrawn from lower elevations. Depending on the depth of the lake, the temperature of water withdrawn from lower elevations will be a few degrees warmer than water withdrawn from close to the surface due to density stratification. Under freezing conditions the heaviest (most dense) water is on the bottom and warmer than surface water.

However, caution has to be exercised in withdrawing water from near the bottom of the lake or below the thermocline (transition zone) unless the treatment plant is equipped to routinely handle water from below the thermocline and the increased treatment costs can be justified.

A prolonged observation over a period of several years and a thorough understanding of local conditions is mandatory for making ongoing decisions concerning depth of withdrawal. (See Section 3.341, "Effects on Raw Water Quality," for more details.)

3.3404 Silt Survey. Silt surveys of most reservoirs should be conducted periodically to get an updated measure of silting as it affects available water storage. These surveys can be done conveniently and with great accuracy by putting a grid on the ice surface. At selected points the water depth can then be measured using sounding equipment or by coring holes through the ice and using a plummet (plumb bob).

3.3405 Recreation Use of Reservoir Ice Surfaces. Ideally, reservoir ice surfaces should not be made accessible for recreational use of any kind, including speed skating, skating, ice sailing, and ice fishing. However, if local authorities approve certain activities on the ice, operators should insist on provisions of certain safeguards against possible pollution. These provisions include time limits put on activities on the ice, proper and close supervision, leak-proof waste containers, adequate toilet facilities and proper care of these facilities.

3.341 Effects on Raw Water Quality

Lakes may be classified according to depth as follows:

1. First order, >200 feet (50 meters);
2. Second order, 25 to 200 feet (7.5 to 60 meters); and
3. Third order, <25 feet (7.5 meters).

Lakes of the first order exhibit relatively little circulation because the large volume of deep water maintains a stable temperature. Third-order lakes have circulation primarily controlled by wind and wave action and thus are usually well circulated in open water times, thus reducing stagnation effects. These lakes are highly susceptible to stagnation once they are covered by ice. Lakes of the second order may have two circulation or turn over periods, one in the spring and one in the fall. Generally speaking, due to their prevalence, the second order lakes are more frequently encountered by operators.

In second order lakes the temperature at the bottom during winter, when the surface is frozen, is not far from that of maximum density (39.2°F or 4°C). The heaviest water is at the bottom, the lightest is at the top, with the intermediate layers arranged in the order of their density. Under these conditions the water is in comparatively stable equilibrium, but is inversely stratified. This is the period of winter stagnation.

The degree of water quality problems is highly affected by the depth of the water inlet. Water from the lowest layer of the lake can become stagnant and the reduction of sulfate to sulfide can occur when the dissolved oxygen is depleted. Such conditions are responsible for odor problems in drinking water. The water from the stagnant zone may also become acidified due to higher concentrations of carbon dioxide which will combine with water to form carbonic acid. If the water becomes sufficiently acidic, reduced forms of iron and manganese may be dissolved from lake bottom materials, resulting in taste and staining problems. After the lake surface is frozen, late algae might bloom causing subsequent severe odor problems. Prudent treatment with copper sulfate in late autumn, when plankton counts are low, may prevent such occurrence of an algal bloom under the ice.

3.342 Summary

During periods of stagnation, deposits of organic matter accumulate at the bottom, ammonia levels increase, decomposition of organic matter takes place, dissolved oxygen disappears and nitrate, sulfate and iron compounds become reduced, free ammonia and nitrite increase and the content of free carbonic acid increases.

A monitoring program which collects samples at various depths to determine dissolved oxygen, metals, and nitrogen values can define the extent of this problem.

To prevent stagnant water at lower elevations from rising to the top during spring circulation (lake turnover), the stagnant water should be discarded whenever possible. This can be accomplished by wasting it through flood gates if the design allows for bottom withdrawal to the flood gates.

3.35 Dam and Reservoir Maintenance

The type and frequency of dam and reservoir maintenance will depend on the size and type of dam. Sometimes these activities are the responsibility of people other than the waterworks operator. The topics listed are presented to give you an idea of some of the items that might be your responsibility. You will have to prepare a program for your facilities depending on what needs to be done.

3.350 Dam Inspection and Maintenance

Dams must be inspected regularly to avoid a catastrophic disaster. Some of the most serious dam failures have been small water storage reservoirs located above subdivisions. Dams should be inspected after heavy rains. Look for evidence of sink holes (holes in the ground), weep holes (water coming out of holes below the dam), and evidence of burrowing animals.

3.351 Reservoir Maintenance

Before draining a reservoir for maintenance, determine when, where and how you will discharge the water in the reservoir. Lower the water level fairly slowly. If the water level drops too quickly the embankments may slip out and be damaged. If the reservoir is lined and the groundwater is high, the lining could be damaged. Lined reservoirs may have to be drained only during periods of low groundwater levels.

Shoreline vegetation such as weeds and cattails should be controlled. Cattails and other weeds can serve as a breeding area for mosquitos. Mechanical or manual techniques can be used to remove and control vegetation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.3X How should the water level in a reservoir be regulated after a reservoir becomes frozen over?

3.3Y How can ice (sheet) buildup or frazzle (granular) ice be prevented from obstructing water flow through intake screens?

3.3Z What water quality problems could develop in a frozen reservoir?

3.4 LABORATORY AND MONITORING PROGRAMS

3.40 Purpose

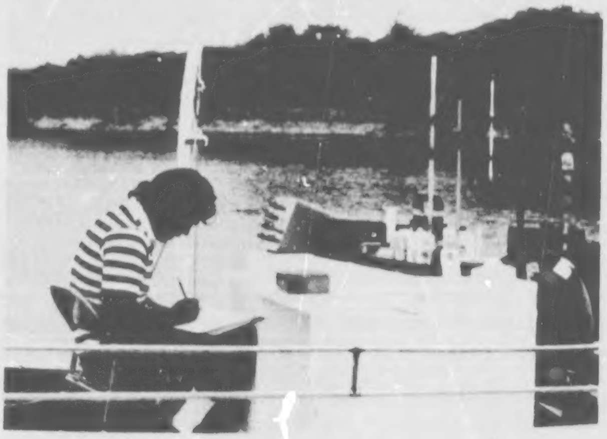
Using the water quality laboratory and related monitoring programs, information can be collected which is essential in developing and evaluating methods of managing water quality in domestic water supply reservoirs. Laboratory and monitoring programs are essential from both an operations and a legal standpoint to determine whether physical, chemical and biological water quality indicators are in compliance with Federal, state and local water quality standards. Water quality data are also an essential tool in optimizing operations of the water treatment plant in relation to treatment costs and techniques, and operation and maintenance programs.

Each agency which operates a surface water supply reservoir must design and operate laboratory and monitoring programs that reflect its own financial and technical resources and need for information. Large municipalities or Federal, state, or county agencies sometimes provide water to hundreds of thousands of persons. Generally, these agencies have much greater analytical and technical capability than the laboratory operated by a local agency which serves small populations. The difference in laboratory capability is often due primarily to the difference in financial resources of the two agencies. The large agency's laboratory may serve several functions such as performing analyses for wastewater treatment facilities, wastewater discharge control programs, and domestic water supply treatment plants as well as collecting data on sources of water supply. The small agency may operate its laboratory and monitoring program primarily for the purpose of managing the surface water supply reservoir and related facilities. There are many more small water supply systems within the United States than there are large municipal or regional systems. The small system operator must be able to manage a water supply as well as large system operators. With proper planning, training, and forethought, the small agency can do a thorough and efficient job of conducting laboratory and monitoring programs within its own financial capabilities.

3.41 Procedures

In many instances, a small reservoir management agency does not have a large enough volume of samples to justify purchasing equipment and training personnel for certain types of analyses. In these cases, it is often much more practical and economical to contract for the work to be performed by a commercial water laboratory or a consulting firm. Arrangements can sometimes be made with county, state, or Federal agencies to have specialized samples collected and analyzed. County, state, and Federal agencies can be particularly helpful when a new or unusual problem develops in the water supply. Examples of types of analyses which may be best performed by an outside or commercial laboratory include trihalomethanes and other organics, general and toxic minerals, radioactivity, pesticides, certain toxic heavy metals (such as lead and mercury), and nutrients.

The agency operating a surface water reservoir should be able to perform analyses which produce data needed on a routine basis for conducting day-to-day operations. Much of the data needed to evaluate physical and chemical conditions within a water supply reservoir can be collected using a single multi-probe instrument (Fig. 3.13). This instrument costs approximately $1,000 to over $10,000, depending on number of probes necessary to measure the water quality indicators and whether the instrument has recording or data transmitting capabilities. Types of data that can be measured at any location and depth within a lake or reservoir with such an instrument include the following: temperature, dissolved oxygen content, *CONDUCTIVITY*[37], pH, and *OXIDATION-REDUCTION POTENTIAL.*[38] A thorough survey of all these water quality indicators can be made in a single working day in most reservoirs. In Lake Casitas, for example, the above data can be collected at depth intervals of 5 feet (1.5 meters) to 20 feet (6 meters) at seven separate stations in approximately six hours. The frequency of the data survey on any given lake is usually related to how rapidly water quality is changing within the lake.



Note above water portion of multi-probe instrument on top of lab bench on left

Fig. 3.13 Water quality monitoring

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[37] *Conductivity. A measure of the ability of a solution (water) to carry an electric current.*

[38] *Oxidation-Reduction Potential. The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.*

If algal blooms are a problem in a particular reservoir, the operating agency should develop laboratory and personnel capabilities for monitoring and identifying algae. The laboratory should be able to develop information on the intensity and extent of algal blooms, the major species of algae involved in any given bloom, and the water quality problems which develop as a result of the bloom. The local agency should be able to collect data on taste and odor conditions related to algal blooms. If chemical methods for controlling algal blooms are used, the local agency should be capable of monitoring chemical dosage levels and residuals.

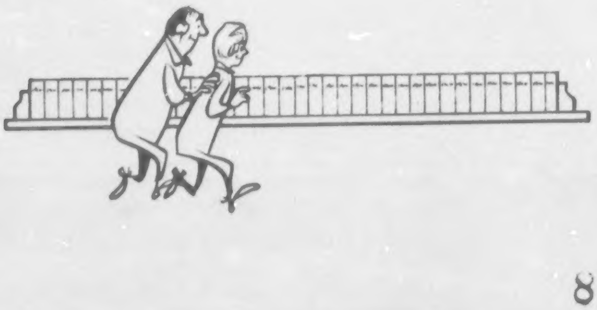
On domestic water supply reservoirs which develop anaerobic zones and their related problems, the local agency may need to monitor iron, manganese, and hydrogen sulfide concentrations. Iron and manganese analyses can be contracted out to a commercial laboratory, but are usually performed "in house" due to the immediate need for the results. The best device for evaluating hydrogen sulfide conditions is often the human nose. If hydrogen sulfide can be smelled in freshly collected unaerated samples, it is present in concentrations objectionable to consumers. However, it is still necessary to measure hydrogen sulfide concentrations to determine improvements. Also, some forms of sulfide may cause odors only after heating.

Information on specific laboratory procedures and training in carrying out these procedures can often be obtained from state health departments. Details on sampling and laboratory procedures are also contained in Chapter 11, "Laboratory Procedures," and also in Volume II, Chapter 21, "Advanced Laboratory Procedures."

3.42 Recordkeeping

One of the most important functions of a well designed laboratory and monitoring program is recordkeeping. This is true whether analyses are performed by the local agency or by some outside laboratory. Records provide the basic foundation upon which management programs are designed, implemented, and evaluated. Records can be used to evaluate rates of water quality deterioration or improvement and have value as a predictive tool in determining when water quality problems will occur or cease.

In many agencies personnel will come and go, but water quality management programs do not suffer if the person who leaves has kept complete and accurate records relating to water quality problems and management programs. Records are of little value if they are only compiled by laboratory personnel and filed away. They must be regularly reviewed and evaluated by persons responsible for making decisions relative to water quality management. Records pertaining to monitoring and laboratory analyses which are necessary to indicate compliance with Federal and State Primary and Secondary Drinking Water Standards are legally required. State and Federal regulations specify how these records should be kept and for how long. Recordkeeping is also a specific requirement of Federal and State Laboratory Certification Programs.



3.43 Safety

Emphasis on knowing and implementing proper safety procedures should be an important part of any laboratory and monitoring program. Specific information on laboratory safety requirements and procedures can be obtained from either state or Federal Occupational Safety and Health Act (OSHA) offices. For additional information on laboratory safety, see Chapter 11, "Laboratory Procedures," and Chapter 20, "Safety," of Volume II of this manual.

Anyone responsible for laboratory or monitoring program safety should try to comply with all state and Federal safety requirements at all times. If this attitude is emphasized in day-to-day operations, then inspections by safety enforcement officers will never be a cause for concern.

Safety hazards involved in water quality sampling may be even greater than those encountered within the laboratory. Most reservoir sampling programs involve the use of a boat, dock, barge or some similar piece of equipment. When conducting sampling, proper flotation equipment (such as life vests) should be worn. People involved in reservoir and stream sampling should at least know how to swim. In many cases, it is advisable to have two persons involved in sampling at a specific location. If sampling is to be carried out on streams and rivers which are a source of supply to the reservoir, additional safety measures may be required.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.4A What are the purposes of water quality laboratory and monitoring programs?

3.4B What types of laboratory analyses should be performed by operating agencies?

3.4C If algal blooms are a problem, what type of laboratory capability should be available to the operating agency?

3.4D What is the main safety hazard encountered during reservoir sampling?

3.5 INTAKE STRUCTURES

3.50 Purpose of Intake Structures

Intake structures and related facilities at water supply reservoirs may be more appropriately referred to as "intake-outlet" facilities, as they take in water from the reservoir for outlet downstream. "Intake structure" and "outlet structure" are terms which are often used interchangeably to describe the same facility. In domestic water supply lakes and reservoirs, these facilities may be used to deliver water to water treatment plants, directly to the distribution system, or for returning water to the river or stream downstream of the reservoir. In some cases, a single intake-outlet system is used to provide for downstream releases to the stream or river and for delivery to the treatment plant or distribution system. In other instances, the facilities which provide for release to the stream or river are entirely separate from those providing service to the domestic water system. River or stream intake structures simply serve to provide raw water for the treatment plant.

Intake facilities should always be constructed on the basis of the specific function which they must serve at a given lake, reservoir, stream or river. They must be capable of supplying the maximum rate of flow required for the water treatment plant. Water supply lakes and reservoirs must also release adequate flow for downstream uses. In situations where intake facilities provide service to pressurized systems, they must be designed so that minimum operating pressures within the system are maintained when the reservoir is drawn down to its minimum operating level. Today greater emphasis is placed on constructing intake structures which permit selection of the depth at which water is drawn from the reservoir, lake, stream, or river.

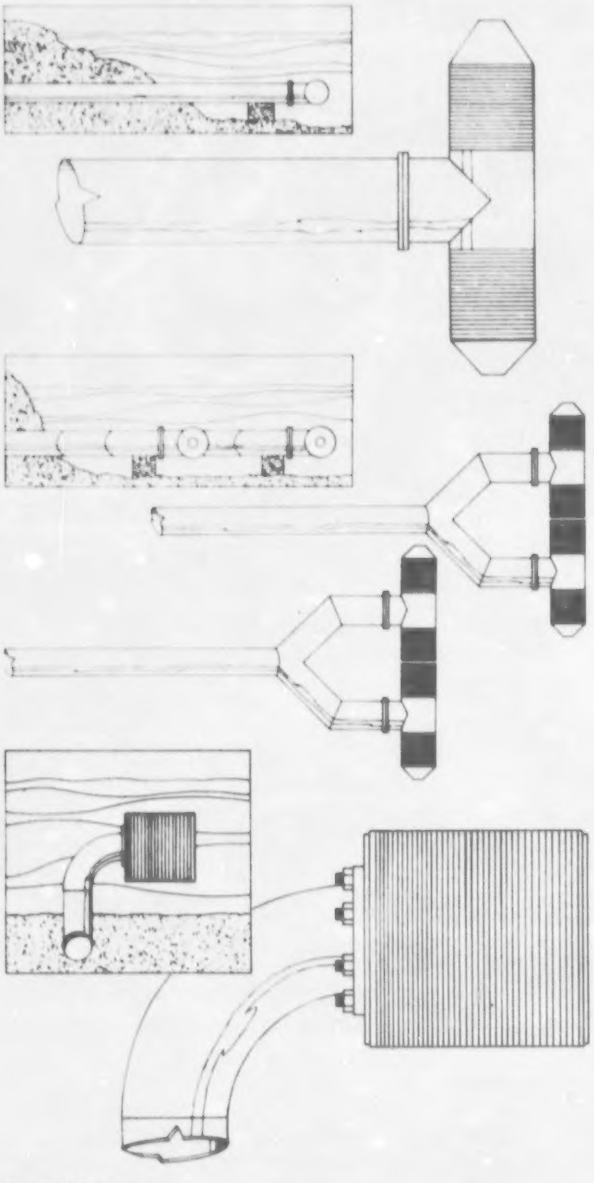
Intake facilities should be constructed in such a manner that they prevent algal scums, trash, logs, and fish from entering the system. To reduce the danger of silt being drawn into the intake system, the water inlet should not be located at low points where silt buildup is anticipated. Always be very careful when operating the lowest level valves if they have not been in use for some time just in case silt buildup has occurred.

One of the more important considerations in the construction of intake facilities is the ease of operation and maintenance over the expected lifetime of the facility. Every intake structure must be constructed with consideration for operator safety. *CATHODIC PROTECTION*[39] systems, which minimize the rate of corrosion of metal parts, are a vital part of many intake systems.

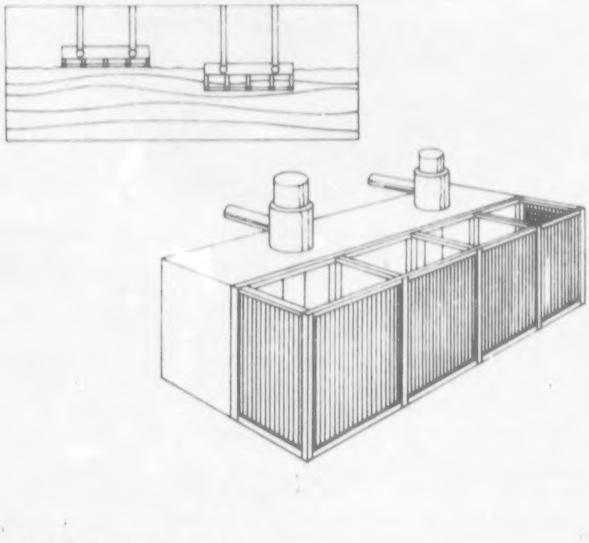
3.51 Types of Intake-Outlet Structures (Figures 3.14, 3.15 and 3.16)

1. Single-Level Intakes. Single- or fixed-level intake systems are commonly used in the distribution systems of domestic water supply streams and reservoirs. The single-level intake is usually located in the deepest portion of the stream or reservoir so that water service can still be provided even when the body of water is down to its minimum operating level. In cases of reservoirs where one intake structure supplies both the domestic water system and releases to streams and rivers, the inlet may be located very close to the bottom so that the reservoir can be drained. Single-inlet intake structures are most suitable in relatively shallow lakes and reservoirs which do not stratify significantly and which exhibit fairly uniform water quality from top to bottom throughout the entire year. These structures may also function well in deeper lakes which are relatively nonproductive and do not experience water quality problems as a result of stratification.

Rivers and streams usually are well mixed and are not stratified. Single-level inlet structures are generally constructed to draw off water from the lowest possible depth in the event of drought conditions.



River Intakes



Canal diversion

Fig. 3.14 River and canal intake facilities (single-level intakes)

(Permission of Johnson Division, UOP Inc.)

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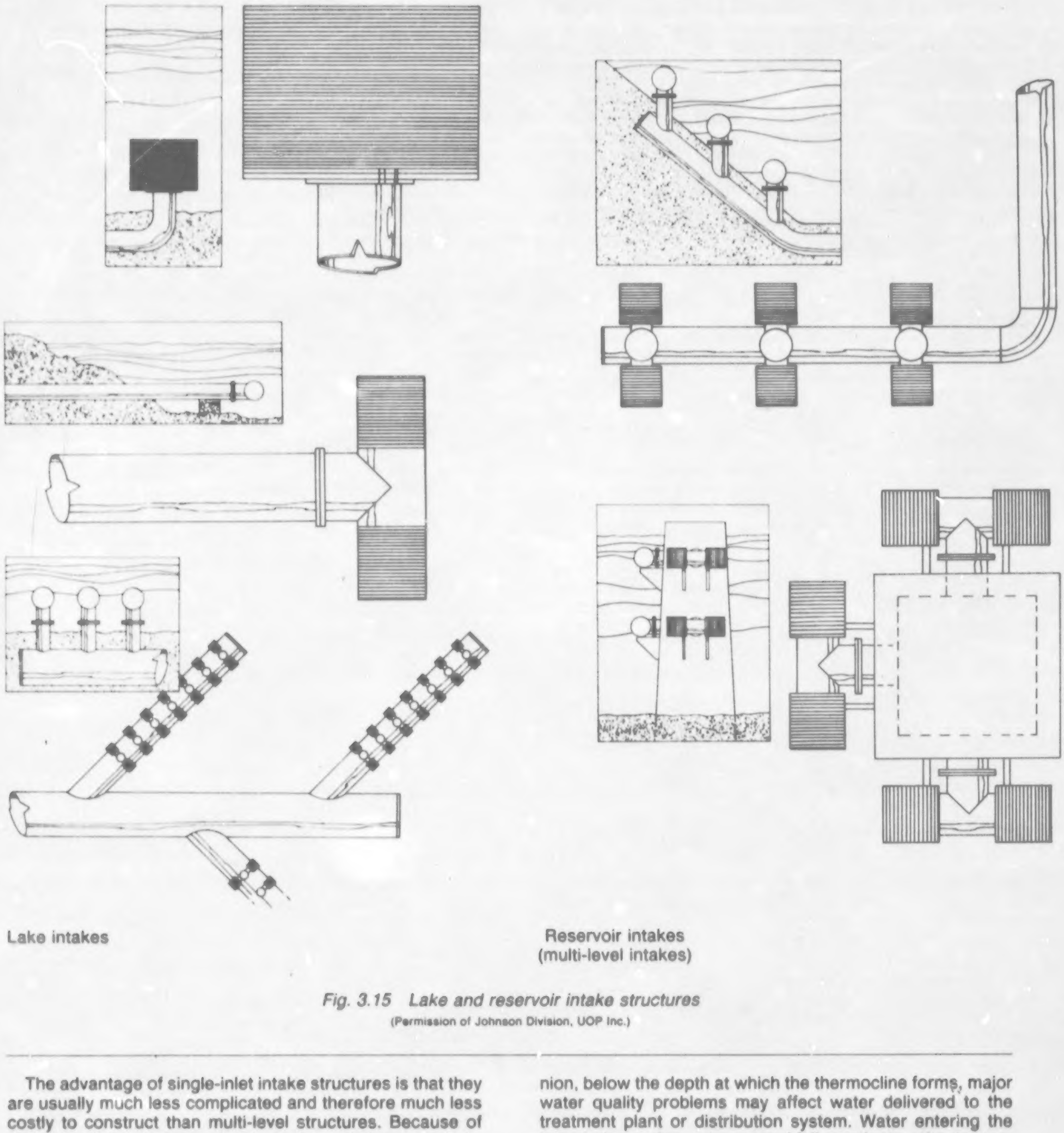
[39] *Cathodic Protection (ca-THOD-ick). A system for prevention of rust, corrosion, and pitting of metal surfaces in contact with water or soil.*



Lake intakes

Reservoir intakes
(multi-level intakes)

Fig. 3.15 Lake and reservoir intake structures

(Permission of Johnson Division, UOP Inc.)

The advantage of single-inlet intake structures is that they are usually much less complicated and therefore much less costly to construct than multi-level structures. Because of their simplicity, they are both easier and less costly to operate and maintain than multi-level intake structures. In deep reservoirs which often remain nearly full, however, it may be difficult to inspect these facilities and perform necessary repairs and maintenance.

Major disadvantages of single fixed-level inlet facilities occur when they are used in deeper, productive (eutrophic) lakes and reservoirs. If the inlet is located within the hypolimnion, below the depth at which the thermocline forms, major water quality problems may affect water delivered to the treatment plant or distribution system. Water entering the inlet during spring, summer and fall months may be anaerobic, may contain high concentrations of iron and/or manganese, and may contain the rotten egg smell caused by the presence of hydrogen sulfide.

Gates or valves which allow water to be taken through the single-level intake may be located either at the point of inlet from the reservoir or stream, in the delivery system at some point downstream, or at both locations.

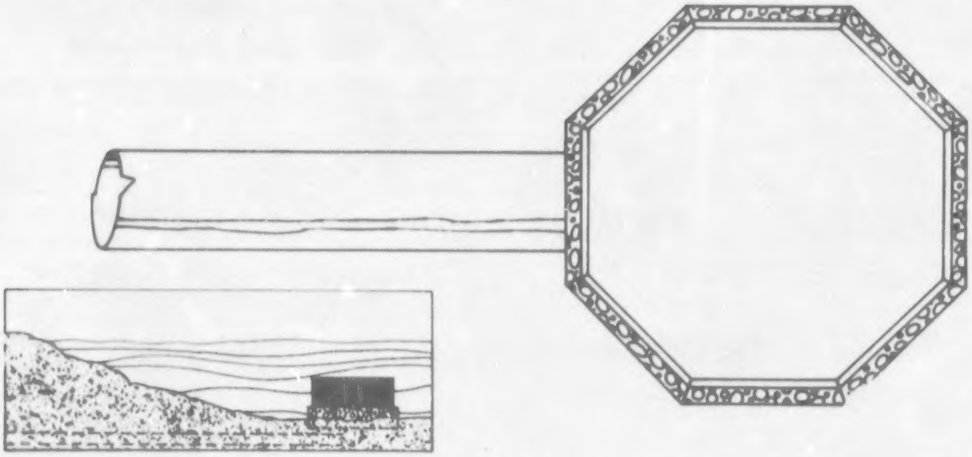


Fig. 3.16 Velocity cap intake structure

(Permission of Johnson Division, UOP Inc.)

2. **Multi-level Intakes.** The most satisfactory intake structures in water supply reservoirs are usually those which have inlets to the system at depths ranging from near the surface to the deeper zones. The major advantage of multi-level intake systems in domestic water reservoirs is that they make it possible to serve water from the depth where the best quality of water is located. To obtain good water quality it may be necessary to draw water from different levels during different seasons of the year. When downstream releases to streams and rivers are requiired, multi-level structures allow for releases from a depth where temperature and dissolved oxygen conditions are acceptable for protecting downstream fish.

Multi-level intake structures are most commonly found in a vertical tower located in the deeper portion of the lake and extending above the water surface. Access to the facility may be by bridge, pier, or boat. Inlet gates may be operated from a deck on top of the tower, from some remote control house, or from another location, depending upon equipment design. Inlet gates are commonly located at specific vertical intervals along the face or faces of the tower. Usually, all inlets feed into the pipeline system which extends from the bottom of the tower to the treatment plant, distribution system, or point of release to a river. Each inlet is equipped with an individually operated gate or valve at the point of inlet. An additional gate or valve is usually located in the pipeline at some point downstream of the intake structure. This arrangement allows for dual control over waters entering the system. If valves or gates at either the inlet or within the pipeline fail, the system can still be shut down.

Some reservoirs contain multi-level intake structures which are inclined rather than vertical. These facilities are commonly located on the inclined face of an earth-fill dam or some similar slope and extend from the maximum water surface level to deeper portions of the reservoir. Inlets with individually operated intake gates or valves are located at intervals along the inclined structure. As with vertical structures, an additional gate or valve is normally located in the pipeline at some point downstream. The inclined intake structure is often a concrete conduit or tunnel with the pipeline located inside and extending from the bottom of the structure downstream to the transmission pipeline. The intake ports extend from the pipeline through the concrete conduit or tunnel and into the reservoir.

For example, the inclined intake structure at Lake Casitas, California, contains nine intake gates located within the reservoir at depth intervals of 24 feet (7.2 m) (see Figure 3.17). When the reservoir is full, water may be drawn from depths ranging from approximately 25 feet (7.5 m) to 217 feet (65 m). Intake gates and related facilities are remotely operated from a control house which is located on top of Casitas Dam at the entrance to the intake structure.

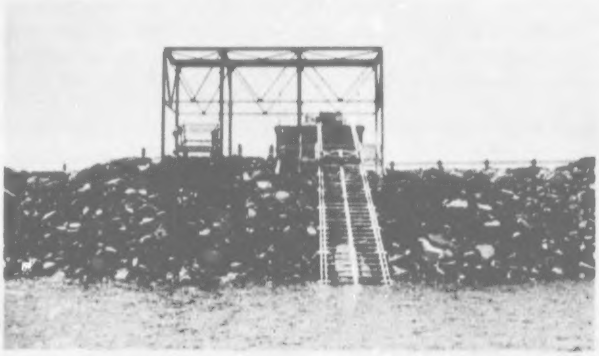


Fig. 3.17 Casitas intake tower

Economy, topography and ease of access are major considerations in determining whether vertical or inclined intake structures should be installed at a given reservoir or stream. In reservoirs or streams that freeze, the effects of ice on intake structures must be considered. Structures may be endangered not only from ice pressures from the side, but also from uplift if a reservoir is filling and the ice mass lifts vertically. In some cases, reservoir reaeration may be used to prevent ice from forming around the intake. See Section 3.34, "Managing Frozen Reservoirs," for additional details.

Selection of the level to withdraw water from a lake or reservoir depends on the water quality in the various layers of water. Once the layer has been selected, regular monitoring is required to continually withdraw water with a good quality. Winds and uniform water temperatures from top to bottom can cause water quality at various depths to change very quickly. To be prepared for changing conditions, the water treatment plant operator should:

1. Maintain a log of wind direction and velocity, at least during the summer months; in warm climates this should be done all year;
2. Be alert for on-shore winds;
3. Maintain close surveillance of threshold odor test results;
4. Be prepared to make necessary changes in treatment plant operation to combat any sudden increases in taste and odor problems; and
5. Do everything possible to keep any water with a bad taste or odor which gets through the treatment plant from getting out into the distribution system.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.5A What is the purpose of "intake-outlet" facilities in domestic water supply lakes and reservoirs?

3.5B Why do some intake systems require cathodic protection?

3.5C What may happen to fish if anaerobic water is released downstream from a reservoir?

3.52 Types of Intake Gates

Any one of several types of intake gates or valves may be used at the inlet to the intake structure or as a control valve within the pipeline system downstream of the intake. The most commonly used types include slide gates (steel or cast iron), gate valves and butterfly valves. Some gates and valves operate only in the fully open or fully closed positions. Others operate as flow-control or regulating valves and gates at any position from fully open to fully closed. Some gates and valves will perform satisfactorily with *HEAD*[40] or pressure on only one side while others are designed to perform best with fairly constant head or pressure on both the upstream and downstream side.

Gates and valves which regulate releases from small impoundments into small distribution facilities are often designed to be operated manually while those in larger installations frequently use electrical power. Both mechanical and hydraulically operated gates and valves are in common use in intake facilities.

3.53 Intake Screens and Trash Racks

Most intake structures in domestic reservoirs, lakes, streams and rivers are installed in such a manner that inlet gates, fish screens, and trash racks are all combined into a single structure. The primary purpose of fish screens, trash racks, log stops, and other protective facilities is to prevent or minimize the entry of foreign material and fish into the intake system.

Intake screens are installed in panels or in cylindrical forms. Usually they are made of stainless steel. Various types of screens include "vee wire," traveling screens, woven wire and slotted plates as shown in Figures 3.18, 3.19 and 3.20. In order to do an effective job, these facilities must be designed so that they are easy to service and maintain, have a relatively long life and do an effective job of protecting the water delivery system. In cases where screens, racks and related structures are constructed of steel or metal, they should be coated with corrosion resistant material. Sometimes it is necessary to install a cathodic protection system in order to extend the life expectancy of these facilities.

The type of screen, trash rack or log stop used in a given intake structure depends upon a number of factors including: depth or depths at which inlets are located; location of the intake structure in relation to where debris accumulates in the reservoir or stream; frequency and intensity of algal scum and/or algal mass accumulations; quantity and type of debris encountered; and the size, depth of distribution, and number of fish, crayfish and other forms of aquatic life. Nonproductive lakes and rivers which contain little aquatic life and receive little or no debris load may only need bar screens. Lakes and rivers with large algal populations might require fine-mesh screens. In lakes, streams and reservoirs which contain large quantities of debris and trash, log booms, hanging screen curtains and similar facilities may be effective in protecting the area surrounding the intake structure. Stream intake structures are usually designed to deflect floating debris away from the inlet ports. This procedure minimizes the time required to clean the screens.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.5D What are the most common types of intake gates?

3.5E List the factors which influence the type of screen needed in a specific reservoir.

3.54 Operation and Maintenance Procedures

Well designed operation and maintenance programs are absolutely necessary if intake structures and related facilities are to perform as intended. Operating criteria, equipment manufacturers' operating instructions, and standard operating procedures should be bound into a manual and used for reference by operators responsible for operating and maintaining intake facilities. If written references containing standard operating and maintenance procedures are

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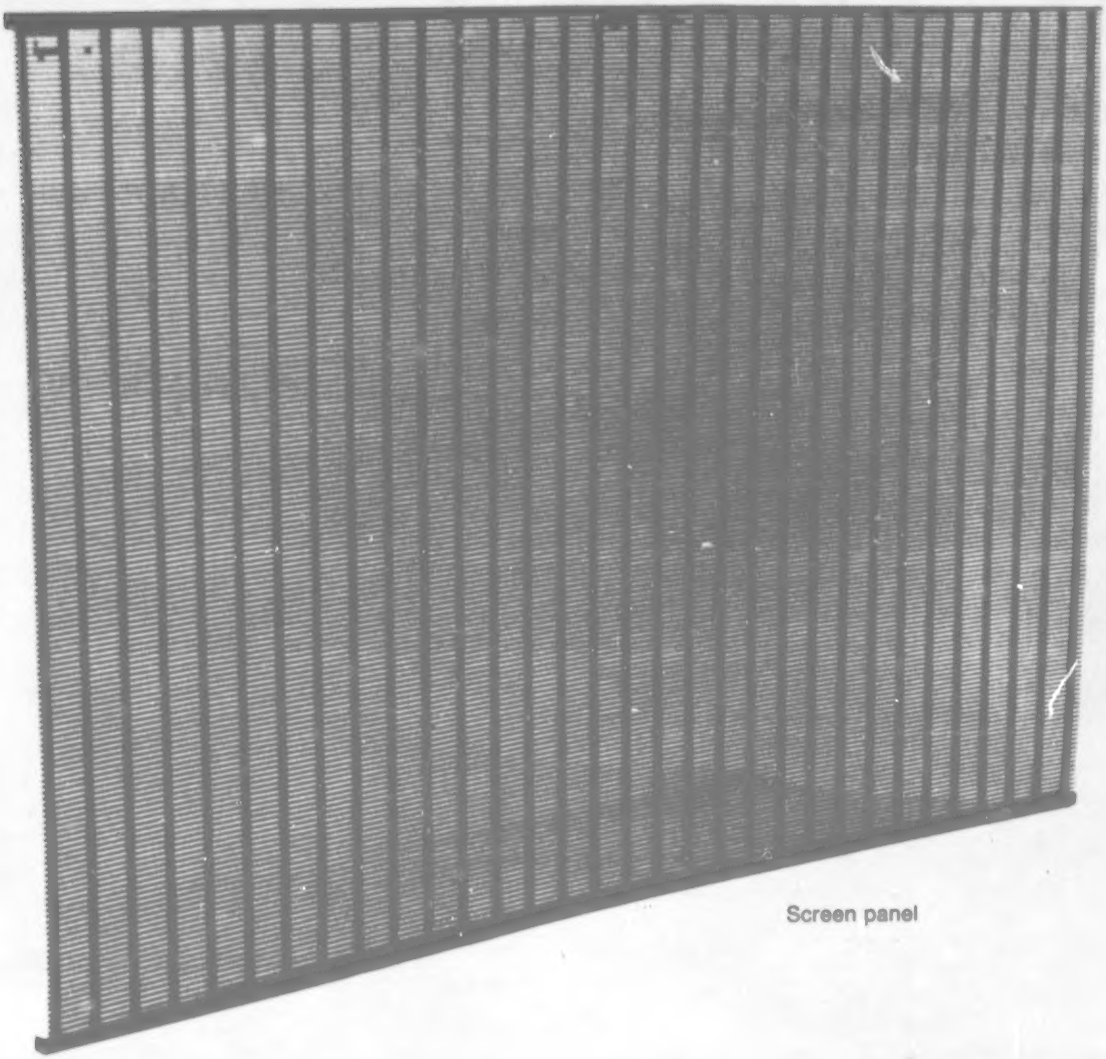
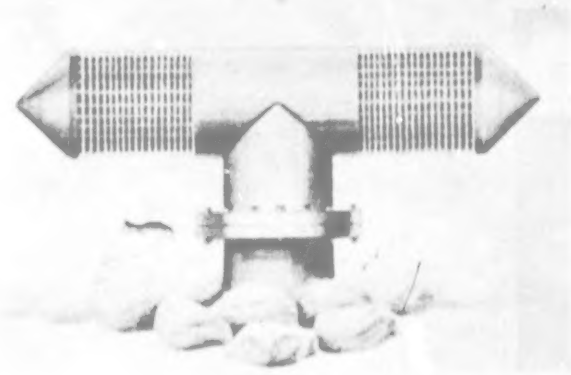
[40] *Head. The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.*



Screen panel



Cylindrical intake screens

Fig. 3.18 Vee wire passive screens
(Permission of Johnson Division, UOP Inc.)

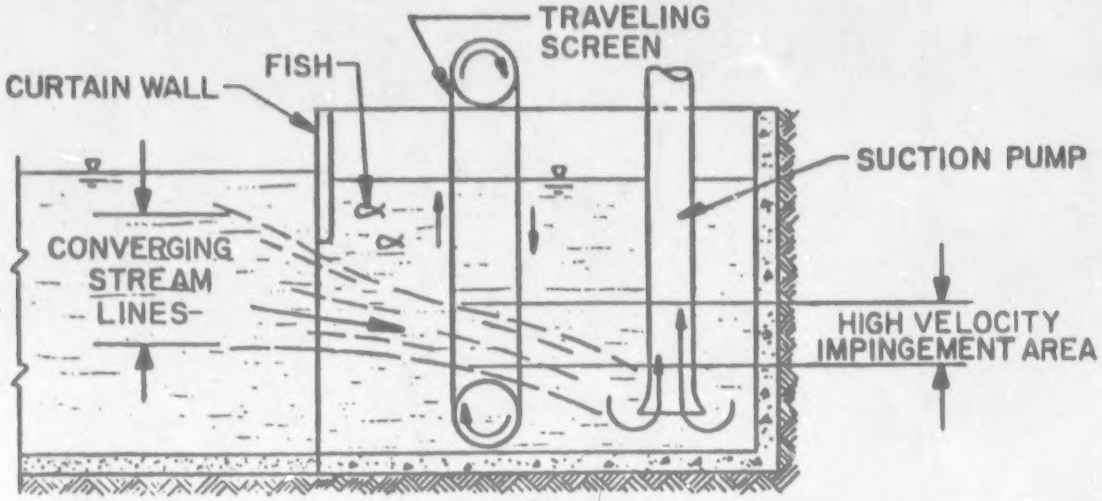
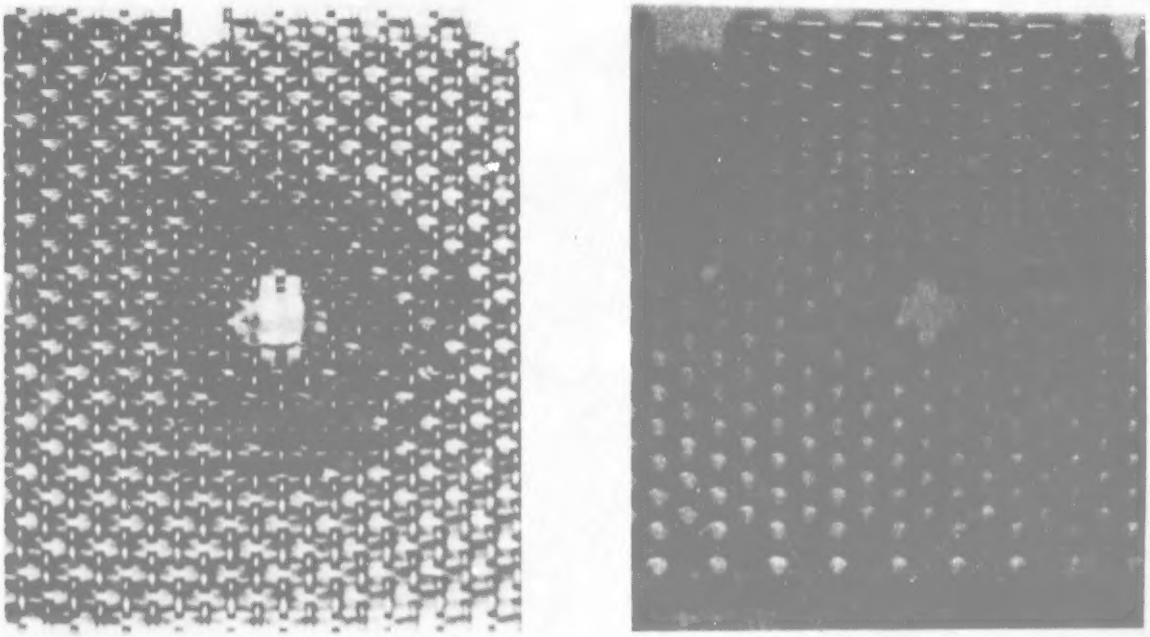

TRAVELING SCREEN
FISH
CURTAIN WALL
SUCTION PUMP
CONVERGING STREAM LINES
HIGH VELOCITY IMPINGEMENT AREA

Fig. 3.19 Traveling screen
(Permission of Johnson Division, UOP Inc.)



Woven wire

Slotted plate

NOTE: Holes are results of corrosion tests.

Fig. 3.20 Intake screens
(Source: Smith, Lawrence W., CLOGGING, CLEANING, AND CORROSION STUDY OF POSSIBLE FISH SCREENS FOR THE PROPOSED PERIPHERAL CANAL. California Department of Water Resources, Sacramento, California, 1982.)

not available for a particular facility, they should be prepared with the assistance of knowledgeable operators, design engineers and equipment manufacturers' representatives.

Screens and trash racks are often designed so that they can be removed for inspection, maintenance and cleaning. Screens can be drawn to the surface, worked on and replaced by one person in a short period of time. Screens and trash racks which are not removable should have some provision for cleaning them in place. Mechanical or hydraulic jet cleaning devices may be used, or divers may be employed to clean the screens.

Intake structures and related facilities should be inspected, operated and tested periodically, preferably at regular intervals. If the reservoir is not drawn down to the level of the deepest intake at periodic intervals, inspections may be conducted by divers (either scuba or hard hat). In recent years, some agencies have used remote controlled video (TV) units to inspect deep water facilities. The submarine-type unit containing the camera is operated from above water and can be maneuvered into any position along the intake structure. A video receiver (TV screen) located on a barge, the shore line, or other above water structure allows operators to complete a detailed inspection of gates, screens, and other structures. Broken, worn and corroded facilities are easily identified. One major advantage of the remotely operated video unit is that it allows a number of persons with different areas of expertise to participate in the inspection. When only divers are used, others must depend entirely on what the divers see or photograph to evaluate conditions.

Proper service and lubrication of intake facilities is particularly important. The following factors are major causes of faulty operation of gates and valves:

1. Settlement or shifting of support structure which could cause binding of gates;
2. Worn, corroded, loose, or broken parts;
3. Lack of use;
4. Lack of lubrication;
5. Vibration;
6. Improper operating procedures;
7. Design errors or deficiencies;
8. Failure of power source or circuit failure; and
9. Vandalism.

Intake screens may be cleaned manually by operators or automatically by mechanical means. Also the screens may be cleaned in place or they may be removed from the inflowing water and cleaned.

If screens are located out in rivers or lakes, the operator may reverse the flow to clean the screen. Some screens have devices which measure the difference in head or head loss between the water surface upstream and downstream from the screen. When a specified head loss is exceeded, a cleaning cycle is started. The cleaning cycle could consist of high pressure water sprays which clean the screen in place, or the screen could be lifted out of the water for cleaning.

Manual methods of cleaning screens include the use of rakes, brooms, bristle brushes and water sprays. Bristle brushes are made of nylon or polypropylene strips of bristles with lengths from 1.5 to 2.5 inches (38 to 64 mm). Screens may be cleaned manually either under water or removed from the flow stream for cleaning. Woven wire and slotted plate screens require operators to develop a cleaning program and schedule.

Screens which are undersized or improperly designed require operators to spend considerable time cleaning the screens. When this happens the operator should budget funds to improve the screening facilities.

If frazzle (granular) ice plugs a screen, see Section 3.34, "Managing Frozen Reservoirs," for cleaning procedures.

Mechanical cleaning devices require a regular maintenance schedule, including lubrication.

3.55 Records

Records containing a history of operations and maintenance performed on intake facilities are vitally important. By keeping a record of when and under what conditions failures or malfunctions occur, it may be possible to take preventive action. Operators come and go, but if adequate records are maintained, new operators are in a better position to perform their jobs properly.

3.56 Safety

When working around intake structures proper safety procedures involving use of electrical and mechanical equipment and water safety should always be observed. Proper safety procedures should be documented and included in the manual containing the standard operating procedures.

3.57 Summary

In summary, properly constructed, operated and maintained intake facilities serve a vital function in the overall domestic reservoir water quality management program. Once good quality water is obtained in the lake, stream, or reservoir, the intake system must be able to deliver water free of debris and trash to treatment or distribution facilities efficiently and satisfactorily.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 87.

3.5F How can screens and trash racks which are not removable be cleaned?

3.5G What should be done if written standard operating and maintenance procedures are not available for a particular intake structure?

3.5H How can inlets that are always under water be inspected?

3.5I List the major causes of faulty operation of gates and valves.

3.6 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read the following sections:

1. A.2 Areas,
2. A.3 Volumes,
3. A.10 Basic Conversion Factors,
4. A.11 Basic Formulas, and
5. A.12 How to Use the Basic Formulas.

Check all of the arithmetic in Sections A.2. Areas, (A.20, A.21, A.22, A.23, A.24, A.25, and A.26) and A.3, Volumes (A.30, A.31, A.32, A.33, and A.34) on an electronic pocket calculator. You should be able to get the same answers.

3.7 ADDITIONAL READING

1. AWWA. *INTRODUCTION TO WATER SOURCES AND TRANSMISSIONS, VOLUME I*, Module 4, "Water Transmission."
2. *NEW YORK MANUAL*, Chapter 6, "Water Quality."
3. *TEXAS MANUAL*, Chapter 4, "Raw Water Quality Management," and Chapter 7, "Pretreatment of Surface Water Supplies."

End of Lesson 2 of 2 Lessons
on
Reservoir Management
and
Intake Structures

DISCUSSION AND REVIEW QUESTIONS

Chapter 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 88. The problem numbering continues from Lesson 1.

15. What happens to algal blooms as a result of a reaeration-destratification program?
16. Why might complete destratification of a reservoir be undesirable?
17. Under what conditions might an agency contract out laboratory analyses?
18. How can the entrance of silt into the intake system be minimized?
19. What is the major advantage of multi-level intake systems in domestic water reservoirs? The major limitation?
20. Why should operators keep records on the operation and maintenance of intake facilities?

SUGGESTED ANSWERS

Chapter 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 50.

3.0A Two common sources of water other than lakes or reservoirs are groundwater and surface water diversions from streams and rivers.

3.0B The methods of treating domestic water delivered from reservoirs range from disinfection only, to direct filtration, to complete treatment which may include softening and activated carbon filtration.

3.0C Deterioration of water quality due to man's presence results from wastewater, agricultural runoff, grazing of livestock, runoff from mining areas, runoff from urban areas, industrial discharges, farming practices, fires and logging operations.

3.0D Natural factors which may lower water quality in reservoirs include climate, watershed and drainage areas, wildfires (lightning) and reservoir geology and vegetation.

Answers to questions on page 51.

3.1A Large quantities of nutrients such as phosphate, nitrate and organic nitrogen compounds are undesirable in a water supply reservoir.

3.1B The three classes of reservoirs based on nutrient content and productivity in terms of animal and plant life are (1) eutrophic, (2) mesotrophic, and (3) oligotrophic.

3.1C An "algal bloom" is a very large increase in plankton (algae) populations over a very short period of time.

Answers to questions on page 52.

3.1D Types of tastes and odors produced by algae include fishy, aromatic, grassy, septic, musty and earthy.

3.1E In many instances, chlorination of a water supply reduces the level of tastes and odors; however, there are some instances in which tastes and odors are more intense following chlorination.

3.1F Tastes and odors may be found in the upper layer of a thermally stratified reservoir, throughout a reservoir during periods of overturn, and throughout deeper waters when a reservoir is frozen over.

Answers to questions on page 54.

3.1G Certain species of algae tend to clog filters and thereby reduce both filtration rates and the duration of filter runs. These conditions cause increased water treatment costs. Under extremely adverse conditions the clogging may occur so frequently that the amount of water used to backwash filters may be greater than the amount of water reaching the distribution system.

3.1H Algal blooms can raise the pH level from near 7 to 9 or above. Increases and decreases in pH are caused by photosynthesis during daylight hours and respiration by algae during darkness.

3.1I As an algal bloom progresses, the dissolved oxygen content at depths where the bloom occurs normally increases markedly as a result of photosynthesis. When the algal cells die, this oxygen is used in the decomposition of the cells by organisms, mainly bacteria, that feed upon (metabolize) the algae cells.

3.1J Increased organic loadings from algal blooms can cause decreased oxygen levels and also increased levels of color and chlorine demand. Also, high trihalomethane levels may occur following free residual chlorination.

Answers to questions on pages 57 and 59.

3.1K When a lake surface warms in the spring or summer, the decrease in density of the warmer water reduces the mixing action within the lake and a barrier is formed between the upper and lower layers.

3.1L Oxygen depletion may be completed anytime from a few weeks to several months after thermal stratification begins.

3.1M Anaerobic conditions in reservoirs cause fish kills, release of hydrogen sulfide (rotten egg odors), and cause iron and manganese in bottom sediments to go into solution (into the water).

3.1N Reservoirs that experience large inflows during short periods may experience sudden and dramatic increases in turbidity, nutrient loading, and organic loading depending upon geological, topographical and vegetative conditions within the watershed.

Answers to questions on page 59.

3.2A Reservoir water quality problems that can be controlled or eliminated by reservoir management programs include: (1) frequency and intensity of algal blooms and the water quality effects associated with these blooms, (2) dissolved oxygen depletion in the metalimnion and hypolimnion, thereby eliminating or controlling iron, manganese and hydrogen sulfide problems, (3) silt loading, (4) high turbidity levels, (5) nutrient loading, and (6) organic loading.

3.2B Reservoir management programs can reduce water treatment costs by controlling tastes and odors and also organic loadings within reservoirs. By controlling algal blooms and silt loadings, chemical costs can be reduced and length of filter runs can be increased. Control of iron and manganese in a reservoir may eliminate the need for control or removal by a treatment plant.

3.2C When dissolved oxygen depletion occurs within the metalimnion and hypolimnion during summer and fall months, trout and salmon are forced up into the warmer epilimnion. The temperatures may be too high for these fish to survive.

Answers to questions on page 60.

3.3A Trees and brush should be removed from areas to be flooded by reservoirs to reduce the organic and nutrient loading which the reservoir will receive as it fills.

3.3B Water quality problems caused by organics released during decomposition include increased color, increased chlorine demand and increased levels of trihalomethanes following chlorination. Nutrients are also released during decomposition which will support an increase in algae production.

3.3C Vegetation can be removed from a reservoir site by mechanical means and hauled from the area for disposal. Also the vegetation can be burned at the site and the ashes hauled out of the area.

Answers to questions on page 61.

3.3D The primary purpose of a watershed management program should be to control, minimize, or eliminate practices within the watershed of a domestic water supply reservoir that would lower water quality.

3.3E Problems caused in reservoirs by raw wastewater contamination include nutrient loading and microbiological contamination.

3.3F Fertilizers can be partially controlled by prohibiting their use on nonessential crops, but are best controlled by public education programs. Leaf analysis on crop plants can determine fertilizer needs and application rates.

3.3G Adverse impacts from soil disturbances due to farming, logging and construction can be minimized by ordinances which limit such activities to those times of the year when the danger of erosion from surface runoff is at a minimum.

Answers to questions on page 62.

3.3H Uses of pesticides and herbicides can be controlled in a watershed by rules and regulations.

3.3I During the runoff period following a fire, large quantities of debris, nutrients, silt and other pollutants may enter a water supply reservoir. Turbidity will usually increase and will have an adverse effect on water treatment plants.

3.3J An agency should consider acquiring title to land in a watershed in order to control or maintain water quality when it is neither politically nor economically feasible to implement controls which are needed to manage the area properly.

Answers to questions on page 63.

3.3K Chemicals are used to prevent or control attached and floating aquatic growths in domestic water supply reservoirs primarily to prevent or control taste and odor problems resulting from algal blooms.

3.3L Chlorine, used as a bactericide or oxidizing agent, may also produce the effects of an algicide.

Answers to questions on page 64.

3.3M The dose of copper sulfate is based on surface area for waters with a methyl orange alkalinity greater than 50 mg/*L* because precipitation of copper makes it ineffective against algae below the surface (copper crystals do not dissolve as they fall through the water). For low alkaline waters, the dose is based on the volume of water.

3.3N Suspended particulate matter in a reservoir reduces the effectiveness of copper as an algicide by affording sites or masses other than algae bodies where the copper is adsorbed.

3.3O The major factor limiting the maximum rate of application of copper sulfate in the source of a domestic water supply is a regulation limiting the concentration of copper in potable water. Another important consideration is the tolerance of fish and other aquatic organisms to copper.

Answers to questions on page 69.

3.3P Three methods of applying copper sulfate compounds to a reservoir include:

1. Dragging burlap bags containing the copper sulfate compounds through the water using a boat,
2. Broadcasting or spreading copper sulfate crystals on the water surface, and
3. Spraying or pumping a copper sulfate solution onto or into the reservoir.

3.3Q The effectiveness of a chemical algae control program is evaluated by monitoring data on type of algae, amount of algae and where they are located prior to, during and following application of chemicals. Careful evaluation must be made to determine if algae die-offs actually occur as a result of the chemical application or if they simply die off due to natural circumstances.

3.3R Safety precautions that should be taken by a person applying copper sulfate in the dry form include special clothing, gloves and breathing apparatus. Also, personal flotation devices must be available on any boat used to spread the chemicals and, in most cases, must be worn while working.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 71.

3.3S The primary purpose of reaeration-destratification programs in domestic water supply reservoirs is usually to eliminate, control or minimize the negative effects on domestic water quality which occur during periods of thermal stratification and dissolved oxygen depletion.

3.3T A reaeration-destratification program can improve water quality by adding dissolved oxygen to zones within a lake which would normally become anaerobic during periods of thermal stratification.

3.3U The two basic methods of maintaining or increasing dissolved oxygen concentrations in reservoirs when thermal stratification exists are (1) destratification and (2) hypolimnetic reaeration.

Answers to questions on page 73.

3.3V Destratification is accomplished by inducing vertical mixing within the reservoir. Such mixing can be achieved either by (1) mechanical means or (2) the use of diffused air which is released near the bottom of the reservoir.

3.3W The rate of dissolved oxygen depletion in a reservoir could vary considerably from one year to the next depending on algal blooms, die-off, and other biological factors. Amount of runoff and available nutrients are also important.

Answers to questions on page 75.

3.3X After a reservoir becomes frozen over, the operator should lower the water level. This will sag the ice cover and reduce the ice pressure on structures and embankments, thus minimizing damage due to ice formation.

3.3Y If ice or frazzle ice build up on an intake screen, apply steam from a portable steam generator.

3.3Z Water quality problems that could develop in frozen reservoirs include:

1. The reduction of sulfate to sulfide when the dissolved oxygen is depleted can cause odor problems,
2. Reduced forms of iron and manganese can cause taste and staining problems, and
3. Late algal blooms can cause odor problems.

Answers to questions on page 76.

3.4A Water quality laboratory and monitoring programs (1) serve as a research tool in managing water quality, (2) help the operator comply with operational and legal guidelines, and (3) help to optimize operations of water treatment plants in relation to treatment costs, techniques, and operation and maintenance programs.

3.4B The operating agency should perform those laboratory analyses which produce data which are needed on a routine basis for conducting the day-to-day operations.

3.4C If algal blooms are a problem, the operating agency should be able to develop specific information on the intensity and extent of algal blooms, the major species of algae involved in any given bloom, and the water quality problems which develop as a result of the bloom. Also the agency should be able to obtain data on taste and odor conditions related to algal blooms. If algae are controlled by chemicals, chemical dosage levels and residuals should be monitored.

3.4D The main safety hazard encountered during reservoir sampling is drowning.

Answers to questions on page 80.

3.5A Intake-outlet facilities deliver water from a reservoir to water treatment plants, directly to the distribution system, or return water to the river or stream downstream of the reservoir.

3.5B Some intake systems require cathodic protection to minimize the rate of corrosion of metal parts.

3.5C Fish kills may result from anaerobic water being released downstream from a reservoir.

Answers to questions on page 80.

3.5D The most common types of intake gates are slide gates, gate valves and butterfly valves.

3.5E The type of screen needed in a specific reservoir depends on depth or depths at which inlets are located, location of the intake structure in relation to debris accumulation in the reservoir, the frequency and intensity of algal scum and/or algal mass accumulations, the quantity and type of debris encountered and the size, depth of distribution, and number of fish, crayfish and other forms of aquatic life.

Answers to questions on page 83.

3.5F Screens and trash racks which are not removable can be cleaned by mechanical or hydraulic jet cleaning devices, or divers may be employed.

3.5G If written standard operation and maintenance procedures are not available for a particular intake structure, the procedures should be prepared with the assistance of knowledgeable operators, design engineers and equipment manufacturers' representatives.

3.5H Inlets that are always under water can be inspected by divers (scuba or hard hat) or by remote controlled video units.

3.5I The major causes of faulty operation of gates and valves are: (1) settlement or shifting of support structure; (2) worn, corroded, loose, or broken parts; (3) lack of use; (4) lack of lubrication; (5) vibration; (6) improper operating procedures; (7) design errors or deficiencies; (8) failure of power source or circuit failure; and (9) vandalism.

OBJECTIVE TEST

Chapter 3. RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Local conditions have little influence on methods of managing lakes and reservoirs used for domestic water supplies.
   1. True
   2. False

2. The amount and type of public use allowed on reservoirs has been standardized by laws and regulations.
   1. True
   2. False

3. Few of the conditions which adversely affect water quality in domestic water supply reservoirs result from the impacts of man's activities upon the environment.
   1. True
   2. False

4. Objectionable tastes and odors in domestic water supplies are often related to the occurrence of algal blooms.
   1. True
   2. False

5. Many conventional water treatment plants are capable of reducing tastes and odors to acceptable levels when operated properly.
   1. True
   2. False

6. Algae can die of oxygen starvation.
   1. True
   2. False

7. In a monomictic lake during winter months, the lake temperature is uniform from top to bottom.
   1. True
   2. False

8. Mixing occurs between the epilimnion and hypolimnion zones in thermally stratified lakes.
   1. True
   2. False

9. Fish kills can result from algae clogging the gills of fish.
   1. True
   2. False

10. Once vegetation removal is accomplished at a reservoir site, regrowth should be controlled until the reservoir is filled.
    1. True
    2. False

11. Chlorination of a water supply may either increase or decrease tastes and odors.
    1. True
    2. False

12. The best tool which can be used for managing watersheds in most cases is the regulatory process.
    1. True
    2. False

13. Phosphate-base fertilizers usually do not cause the water quality problems caused by nitrogen fertilizers because of the soil-binding characteristics of phosphate compounds.
    1. True
    2. False

14. All algae react the same way to copper sulfate.
    1. True
    2. False

15. Destratification appears to increase the number of algal blooms in reservoirs.
    1. True
    2. False

16. With complete destratification, temperatures in a reservoir will be uniform from top to bottom.
    1. True
    2. False

17. Through proper design and operation, reservoir destratification systems can be used to manipulate temperatures and dissolved oxygen content to desired levels.
    1. True
    2. False

18. The operator of a small water supply system must be able to manage the watershed as well as operators of large systems.
    1. True
    2. False

19. Records are very valuable when they are only completed and filed by lab personnel.
    1. True
    2. False

20. The inlet to a single-level intake is usually located near the water surface.
    1. True
    2. False

MULTIPLE CHOICE

21. Nutrients act as a (n) ____________ in a lake.
    1. Algicide
    2. Chemical stabilizer
    3. Destratifier
    4. Fertilizer
    5. Purifier

22. Reservoirs which are rich in nutrients and very productive in terms of aquatic animal and plant life are commonly referred to as
    1. Dimictic.
    2. Eutrophic.
    3. Mesotrophic.
    4. Oligotrophic.
    5. Thermophylic.

23. What problems may be created for operators by algal blooms in domestic water supply reservoirs?
    1. Dissolved oxygen depletion
    2. Increased pH which reduce chlorination efficiency
    3. Increased organic loadings
    4. Shortened filter runs
    5. Tastes and odors

24. What water quality problems are caused by iron and manganese in drinking water?
    1. Dirty water
    2. Dissolved oxygen depletion
    3. High coliform counts
    4. Staining clothes
    5. Staining porcelain fixtures

25. Proper management can increase recreational values of a reservoir by
    1. Controlling man's activities on the watershed.
    2. Increasing the rate of oxygen depletion.
    3. Reducing large mats of algae.
    4. Reducing scums of algae.
    5. Removing vegetation before flooding.

26. Trees and brush should be removed from areas to be flooded by reservoirs to reduce the ____________ loading.
    1. Iron and manganese
    2. Nutrient
    3. Organic
    4. Silt
    5. Turbidity

27. Anaerobic conditions in the hypolimnion of a reservoir can cause
    1. Algal scums.
    2. Fish kills.
    3. High organic loadings.
    4. Iron and manganese problems.
    5. Rotten egg odors.

28. Algal blooms in lakes and reservoirs can be controlled by
    1. Chemical methods.
    2. Limiting nutrient recycling.
    3. Preventing nutrient inflow.
    4. Removal of algae by filtration.
    5. Removal of nutrients by filtration.

29. Which of the following water quality indicators have a significant impact on the efficiency of copper sulfate as an algicide?
    1. Alkalinity
    2. Dissolved oxygen
    3. pH
    4. Suspended matter
    5. Water temperature

30. Which chemical is used to make copper sulfate effective in highly alkaline waters (greater than 50 mg/*L* alkalinity)?
    1. Citric acid
    2. Hydrochloric acid
    3. Nitric acid
    4. Phosphoric acid
    5. Sulfuric acid

31. The reasons for using destratification programs in domestic water supply reservoirs including improving
    1. Aesthetics.
    2. Fisheries.
    3. Hydroelectric power production.
    4. Recreational values.
    5. Water quality.

32. Important water quality indicators that should be considered in a lake destratification program include
    1. Carbon dioxide.
    2. Coliforms.
    3. Dissolved oxygen.
    4. Hardness.
    5. Temperature.

33. Factors affecting watershed management programs include
    1. Intake structures.
    2. Size of watershed.
    3. Topography.
    4. Vegetative conditions.
    5. Water quality problems.

34. Which of the following watershed practices can affect water quality in a water supply reservoir?
    1. Control of land use
    2. Livestock grazing
    3. Oil and gas exploration and drilling
    4. Septic-tank leaching systems
    5. Soil conservation programs

35. Water quality laboratory analyses which may be best performed by commercial laboratories include
    1. Dissolved oxygen.
    2. Pesticides.
    3. Radioactivity.
    4. Temperature.
    5. Trihalomethanes.

36. Intake facilities should prevent ____________ from entering a water supply system.
    1. Algal scums
    2. Fish
    3. Hardness
    4. Iron and manganese
    5. Tastes and odors

37. Water quality problems caused by anaerobic water entering the intake-inlet include high concentrations of
    1. Dissolved oxygen.
    2. Hardness.
    3. Hydrogen sulfide.
    4. Iron.
    5. Manganese.

38. Types of intake screens include
    1. Burlap sacks.
    2. Slotted plates.
    3. Vee wire.
    4. Window screens.
    5. Woven wire.

39. Methods of cleaning intake screens include
    1. Brushing with bristle brushes.
    2. Drying and brushing.
    3. Jetting with high pressure water.
    4. Reversing the flow.
    5. Vacuuming up the debris.

40. What is the surface area of a rectangular settling basin 60 feet long and 15 feet wide?
    1. 90 square feet
    2. 360 square feet
    3. 400 square feet
    4. 500 square feet
    5. 900 square feet

41. What is the surface area of a circular clarifier 40 feet in diameter?
    1. 314 square feet
    2. 1256 square feet
    3. 1600 square feet
    4. 2512 square feet
    5. 5024 square feet

42. Calculate the volume in cubic feet of a rectangular settling basin 8 feet deep, 15 feet wide and 50 feet long.
    1. 120 cu ft
    2. 480 cu ft
    3. 900 cu ft
    4. 4800 cu ft
    5. 7200 cu ft

43. Calculate the volume in cubic feet of a circular clarifier 7 feet deep and 40 feet in diameter. Select the answer closest to your answer.
    1. 7,200 cu ft
    2. 8,800 cu ft
    3. 11,200 cu ft
    4. 24,800 cu ft
    5. 35,200 cu ft

44. How many pounds of copper sulfate will be needed to dose a reservoir with 0.5 mg/*L* copper? The reservoir volume is 20 million gallons. The copper sulfate is 25 percent copper. Select the closest answer.
    1. 125 pounds
    2. 165 pounds
    3. 335 pounds
    4. 835 pounds
    5. 1335 pounds

END OF OBJECTIVE TEST

CHAPTER 4

COAGULATION AND FLOCCULATION

by

Jim Beard

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OBJECTIVES

Chapter 4. COAGULATION AND FLOCCULATION

Following completion of Chapter 4, you should be able to:

1. Describe the need for coagulation and flocculation,
2. Perform a jar test,
3. Select the proper coagulant and determine the dosage,
4. Adjust chemical feed rates,
5. Select optimum speeds for flash mixers and flocculators,
6. Collect samples from the coagulation and flocculation basins,
7. Start up and shut down a coagulation/flocculation process, and
8. Operate and maintain coagulation/flocculation processes.

GLOSSARY

Chapter 4. COAGULATION AND FLOCCULATION

ALKALINITY (AL-ka-LIN-it-tee) ALKALINITY

The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

ANIONIC POLYMER (AN-eye-ON-ick) ANIONIC POLYMER

A polymer having negatively charged groups of ions; often used as a filter aid and for dewatering sludges.

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated or a chemical solution is prepared, and the tank is emptied. The tank may then be filled and the process repeated.

BUFFER BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.

CATIONIC POLYMER CATIONIC POLYMER

A polymer having positively charged groups of ions; often used as a coagulant aid.

COAGULANTS (co-AGG-you-lents) COAGULANTS

Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the water by settling, skimming, draining or filtering.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The clumping together of very fine particles into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

COLLOIDS (CALL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

COMPOSITE (PROPORTIONAL) SAMPLE (come-PAH-zit) COMPOSITE (PROPORTIONAL) SAMPLE

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

CONTINUOUS SAMPLE CONTINUOUS SAMPLE

A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples. Frequently, several taps (faucets) will flow continuously in the laboratory to provide test samples from various places in a water treatment plant.

DETENTION TIME DETENTION TIME

(1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow.

(2) The actual time in hours, minutes or seconds that a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber. In storage reservoirs, detention time is the length of time entering water will be held before being drafted for use (several weeks to years, several months being typical).

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

FLOC FLOC

Clumps of bacteria and particulate impurities that have come together and formed a cluster. Found in flocculation tanks and settling or sedimentation basins.

FLOCCULATION (FLOCK-you-LAY-shun) FLOCCULATION

The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing.

GRAB SAMPLE GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

HEAD LOSS HEAD LOSS

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses.

INORGANIC INORGANIC

Material such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

JAR TEST JAR TEST

A laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with different chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to *ESTIMATE* the minimum or ideal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of solids is observed. The dose of chemicals that provides satisfactory settling removal of turbidity and/or color is the dose used to treat the water being taken into the plant at that time. When evaluating the results of a jar test, the operator should also consider the floc quality in the flocculation area and the floc loading on the filter.

LAUNDERING WEIR (LAWN-der-ing weer) LAUNDERING WEIR

Sedimentation basin overflow weir. A plate with V-notches along the top to assure a uniform flow rate and avoid short-circuiting.

MOLECULAR WEIGHT MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
0	16	4	64
			98

MONOMER (MON-o-MER) MONOMER

A molecule of low molecular weight capable of reacting with identical or different monomers to form polymers.

NONIONIC POLYMER (NON-eye-ON-ick) NONIONIC POLYMER

A polymer that has no net electrical charge.

ORGANIC ORGANIC

Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

PARTICLE COUNT PARTICLE COUNT

The results of a microscopic examination of treated water with a special "particle counter" which classifies suspended particles by number and size.

PARTICULATE (par-TICK-you-let) PARTICULATE

A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

PLAN VIEW PLAN VIEW

A diagram or photo showing a facility as it would appear when looking down on the top of it.

POLYELECTROLYTE (POLY-ee-LECK-tro-lite) POLYELECTROLYTE

A high-molecular-weight (relatively heavy) substance having points of positive or negative electrical charges that is formed by either a natural or man-made process. Natural polyelectrolytes may be of biological origin or derived from starch products and cellulose derivatives. Man-made polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Often called a POLYMER.

POLYMER POLYMER

A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

PROFILE PROFILE

A drawing showing elevation plotted against distance, such as the vertical section or side view of a pipeline.

RAW WATER RAW WATER

(1) Water in its natural state, prior to any treatment.

(2) Usually the water entering the first treatment process of a water treatment plant.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

SIMULATE SIMULATE

To reproduce the action of some process, usually on a smaller scale.

SLUDGE (sluj) SLUDGE

The settleable solids separated from water during processing.

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle, substance, or chemical solution in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Particulates in raw water may have a specific gravity of 1.005 to 2.5.

TURBIDIMETER TURBIDIMETER

An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

NEPHELOMETRIC
DEFLECTED LIGHT

TURBIDITY UNITS (TU) TURBIDITY UNITS

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

WEIR (weer) WEIR

(1) A wall or plate placed in an open channel and used to measure the flow of water. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used.

(2) A wall or obstruction used to control flow (from settling tanks and clarifiers) to assure uniform flow rate and avoid short-circuiting.

WET CHEMISTRY WET CHEMISTRY

Laboratory procedures used to analyze a sample of water using liquid chemical solutions (wet) instead of, or in addition to, laboratory instruments.

CHAPTER 4. COAGULATION AND FLOCCULATION

(Lesson 1 of 3 Lessons)

4.0 NATURE OF PARTICULATE IMPURITIES IN WATER

PARTICULATE[1] impurities in water result from land erosion, pickup of minerals, and the decay of plant material. Additional impurities are added by airborne contamination, industrial discharges, and by animal wastes. Thus, surface water sources, polluted by man and nature, are likely to contain suspended and dissolved organic (plant or animal origin) and inorganic (mineral) material, and biological forms such as bacteria and plankton.

These particulates (commonly called suspended solids) cover a broad size range. Larger sized particles such as sand and heavy silts can be removed from water by slowing down the flow to allow for simple gravity settling. These particles are often called *SETTLEABLE SOLIDS*. Settling of larger sized particles occurs naturally when surface water is stored for a sufficient period of time in a reservoir or a lake. Smaller sized particles, such as bacteria and fine clays and silts, do not readily settle and treatment is required to produce larger particles that are settleable. These smaller particles are often called *NONSETTLEABLE SOLIDS* or *COLLOIDAL*[2] *MATTER*.

4.1 NEED FOR COAGULATION AND FLOCCULATION

The purpose of coagulation and flocculation is to remove particulate impurities, especially nonsettleable solids, and color from the water being treated. Nonsettleable particles in water are removed by the use of *COAGULATING* chemicals. These chemicals cause the particles to clump together forming floc. When pieces of floc clump together, they form larger, heavier floc which will settle out.

In the *COAGULATION PROCESS*,[3] chemicals are added which will initially cause the particles to become destabilized and clump together. The particles gather together to form particles in the *FLOCCULATION PROCESS*[4] (see Figure 4.1).

With few exceptions, surface waters require treatment to remove particulate impurities and color before distribution of water to the consumer.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 133.

4.0A What is the purpose of coagulation and flocculation?

4.1A What happens in the coagulation and flocculation process?

4.2 COAGULATION

4.20 Process Description

The term coagulation describes the effect produced when certain chemicals are added to raw water containing slowly settling or nonsettleable particles. The small particles begin to form larger or heavier floc which will be removed by sedimentation and filtration.

The mixing of the coagulant chemical and the raw water to be treated is commonly referred to as *FLASH MIXING*. The primary purpose of the flash mix process is to rapidly mix and equally distribute the coagulant chemical throughout the water. The entire process occurs in a very short time (several seconds), and the first results are the formation of very small particles.

4.21 Coagulants

In practice, chemical coagulants are referred to either as primary coagulants or as coagulant aids. Primary coagulants are used to cause the particles to become destabilized and begin to clump together, while the purpose of coagulant aids is to add density to slow-settling flocs and add toughness so the floc will not break up in the following processes. In view of this definition, coagulant aids could be called flocculation or sedimentation aids.

Metallic salts (aluminum sulfate (commonly called alum), ferric sulfate, ferrous sulfate) and synthetic (man-made) organic *POLYMERS*[5] (cationic, anionic, nonionic) are commonly used as coagulation chemicals in water treatment because they are effective; relatively low cost; available; and easy to handle, store, and apply.

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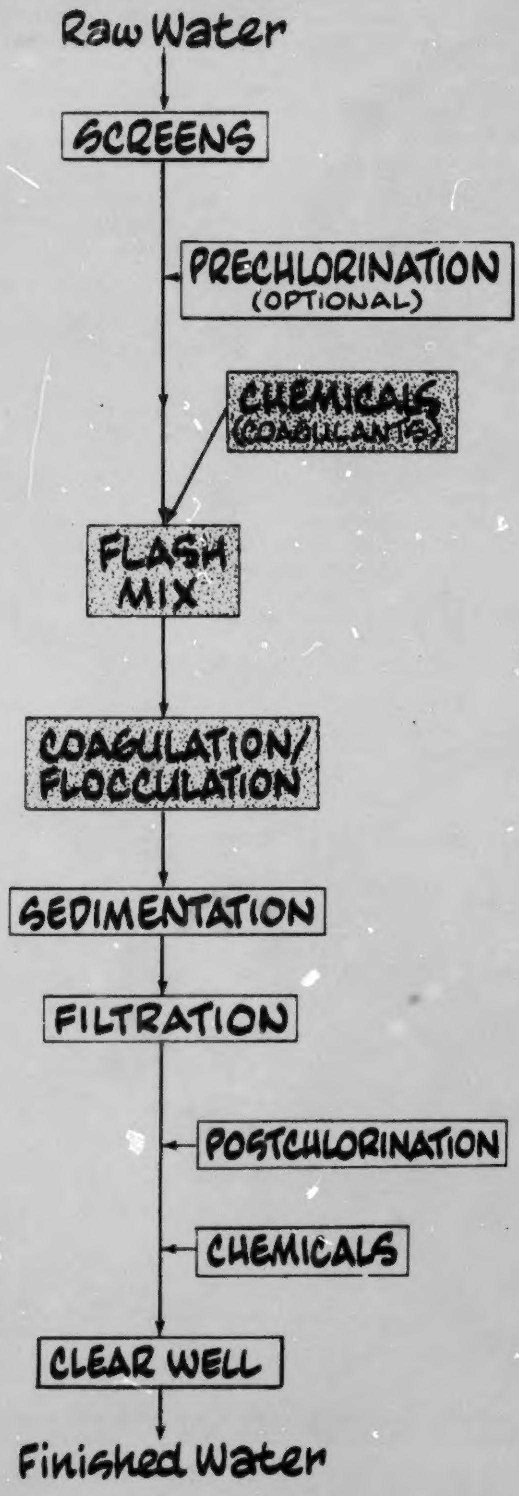
[1] *Particulate (par-TICK-you-let). A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.*

[2] *Colloids (CALL-loids). Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have an electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.*

[3] *Coagulation (co-AGG-you-LAY-shun). The clumping together of very fine particles into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.*

[4] *Flocculation (FLOCK-you-LAY-shun). The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing.*

[5] *Polymer. A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.*


Raw Water
SCREENS
PRECHLORINATION (OPTIONAL)
CHEMICALS (COAGULANTS)
FLASH MIX
COAGULATION/ FLOCCULATION
SEDIMENTATION
FILTRATION
POSTCHLORINATION
CHEMICALS
CLEAR WELL
Finished Water

TREATMENT PROCESS	PURPOSE
Raw Water	
SCREENS	Removes leaves, sticks, fish & other large debris.
PRECHLORINATION (OPTIONAL)	Kills most disease causing organisms & helps control taste and odor causing substances.
CHEMICALS (COAGULANTS)	Causes very fine particles to clump together into larger particles.
FLASH MIX	Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water.
COAGULATION/ FLOCCULATION	Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration processes.
SEDIMENTATION	Settles out larger suspended particles.
FILTRATION	Filters out remaining suspended particles.
POSTCHLORINATION	Kills disease-causing organisms. Provides chlorine residual for distribution system.
CHEMICALS	Controls corrosion.
CLEAR WELL	Provides chlorine contact time for disinfection. Stores water for high demand.
Finished Water	

Fig. 4.1 Process diagram of typical plant

When metallic salts such as aluminum sulfate or ferric sulfate are added to water, a series of reactions occur with the water and with other ions in the water. Sufficient chemical quantities must be added to the water to exceed the solubility limit of the metal hydroxide, resulting in the formation of a precipitate (floc). The resulting floc formed will then adsorb on particles (turbidity) in the water.

The synthetic organic polymers (cationic, anionic, nonionic) used in water treatment consist of a long chain of small subunits or "monomers." The polymer chain can have a linear or branched structure, ranging in length from a fraction of a micron (one micron = 0.001 millimeter) to as much as 10 microns. The total number of monomers in a synthetic polymer can be varied to produce materials of different *MOLECULAR WEIGHTS,*[6] which vary from about 100 to 10,000,000.

The polymers normally used in water treatment contain ionizable groups on the monomeric units (carboxyl, amino, sulfonic groups), and are commonly referred to as "polyelectrolytes." Polymers with positively charged groups on the monomeric units are referred to as "cationic" polyelectrolytes, while polymers with negatively charged groups are called "anionic" polyelectrolytes. Polymers without ionizable groups are referred to as "nonionic" polymers.

Cationic polymers have the ability to adsorb on negatively charged particles (turbidity) and neutralize their charge. They can also form an interparticle bridge which collects (entraps) the particles. Anionic and nonionic polymers also form interparticle bridges, which aid in the collection and removal of particles from water.

While alum is perhaps the most commonly used coagulant chemical, cationic polymers are used in the water treatment field as both a primary coagulant (in place of alum or other metallic salts) and as a coagulant aid (used in conjunction with alum and other metallic salts). Anionic and nonionic polymers have also proven to be effective in certain applications as coagulant aids and filter aids.

One of the problems that will confront the water treatment plant operator in the selection of an appropriate polymer is that there is a tremendous number of polymers available in the marketplace, and no universal evaluation method has been generally adopted for polymer selection. Thus, the operator should use caution in the selection and use of polymers and should take note of the following considerations regarding polymer use:

1. Polymer overdosing will adversely affect coagulation efficiency and when used as a filter aid, overdosing can result in accelerated head loss buildup;
2. Not all water supplies can be treated with equal success;
3. Some polymers lose their effectiveness when used in the presence of a chlorine residual; and
4. Some polymers are dosage limited. The operator should obtain the maximum safe dosage which can be applied from the specific chemical manufacturer.

Since universal standards do not exist for the selection and use of organic polymers, the operator should be careful to select only those products which have been approved by state and federal regulatory agencies for use in potable water treatment. The chemical supplier should be required to provide written evidence of this approval. Many chemical suppliers have considerable experience in dealing with many types of water and may be able to recommend the "best" polymer for your plant.

The U.S. Environmental Protection Agency publishes a list of polymers approved for potable water usage. This list contains the name of the manufacturer and the maximum concentration recommended. A list of primary coagulants and coagulant aids is shown in Table 4.1.

TABLE 4.1 CHEMICAL COAGULANTS USED IN WATER TREATMENT

CHEMICAL NAME	CHEMICAL FORMULA	PRIMARY COAGULANT	COAGULANT AID
ALUMINUM SULFATE	$Al_2(SO_4)_3 \cdot 14H_2O$	X	
FERROUS SULFATE	$FeSO_4 \cdot 7H_2O$	X	
FERRIC SULFATE	$Fe_2(SO_4)_3 \cdot 9H_2O$	X	
FERRIC CHLORIDE	$FeCl_3 \cdot 6H_2O$	X	
CATIONIC POLYMER	Various	X	X
CALCIUM HYDROXIDE	$Ca(OH)_2$	X*	X
CALCIUM OXIDE	CaO	X*	X
SODIUM ALUMINATE	$Na_2Al_2O_4$	X*	X
BENTONITE	Clay		X
CALCIUM CARBONATE	$CaCO_3$		X
SODIUM SILICATE	Na_2SiO_3		X
ANIONIC POLYMER	Various		X
NONIONIC POLYMER	Various		X

* *Used as primary coagulants only in water-softening processes.*

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[6] ***Molecular Weight.*** *The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.*

Element	*Atomic Weight*	*Number of Atoms*	*Molecular Weight*
H	*1*	*2*	*2*
S	*32*	*1*	*32*
O	*16*	*4*	*64*
			98

4.22 Basic Coagulant Chemistry

The theory of coagulation is very complex. However, this discussion of coagulation chemistry is presented to help you understand the coagulation process.

Coagulation is a physical and chemical reaction occurring between the *ALKALINITY*[7] of the water and the coagulant added to the water which results in the formation of insoluble flocs (floc that will not dissolve).

For a specific coagulant (such as aluminum sulfate or alum), the pH of the water determines which hydrolysis species (chemical compounds) predominate. Lower pH values tend to favor positively charged species which are desirable for reacting with negatively charged colloids and particulates, forming insoluble flocs and removing impurities from the water.

The best pH for coagulation usually falls in the range of pH 5 to 7. The proper pH range must be maintained because coagulants generally react with the alkalinity in water. Residual alkalinity in the water serves to *BUFFER*[8] (prevent pH from changing) the system and aids in the complete precipitation of the coagulant chemicals. The amount of alkalinity in the source (raw) water is generally not a problem unless the alkalinity is very low. Alkalinity may be increased by the addition of lime or soda ash.

Polymers are generally added in the coagulation process to stimulate or improve the formation of insoluble flocs.

Generally, the operator has no control over the pH and alkalinity of the source water. Hence, evaluation of these water quality indicators may play a major role in selecting the type of chemical coagulants to be used at a particular water treatment plant, or in changing the type of coagulant normally used if significant changes in pH and alkalinity occur in the raw water.

In some instances the natural alkalinity in the raw water may be too low to produce complete precipitation of alum. In these cases lime is often added to assure complete precipitation. Care must be used to keep the pH within the desired range.

Overdosing as well as underdosing of coagulants may lead to reduced solids removal efficiency. This condition can be corrected by carefully performing *JAR TESTS*[9] and verifying process performance after making any changes in the operation of the coagulation process.

4.23 Process Performance Considerations

4.230 Methods of Mixing

In modern water treatment plants, it is desirable to complete the coagulation reaction (mixing of chemicals into the water) in as short a time as possible — preferably within a period of several seconds since the reaction time is short. To accomplish the mixing of the chemicals with the water to be treated, several methods can be used (see Figure 4.2):

1. Hydraulic mixing using flow energy in the system,
2. Mechanical mixing,
3. Diffusers and grid systems, and
4. Pumped blenders.

4.231 Types of Mixers

In order for complete coagulation and flocculation to take place, the coagulant must make contact with all of the suspended particles. This is accomplished by "flash mixing."

Mixing can be satisfactorily achieved with a number of different types of mixing devices. Hydraulic mixing with baffles or throttling valves works well in systems which have sufficient water velocity (speed) to cause turbulence in the water being treated. The turbulence in the flowing water mixes the chemicals with the water.

Mechanical mixers (paddles, turbines, and propellers) are frequently used in coagulation facilities. Mechanical mixers are versatile and reliable; however, they generally use the greatest amount of electrical energy for mixing the coagulant with the water being treated.

Diffusers and grid systems consisting of perforated tubes or nozzles can be used to disperse the coagulant into the water being treated. These systems can provide uniform (equal) distribution of the coagulant over the entire coagulation basin. However, they are generally sensitive to flow changes and may require frequent adjustments to produce the proper amount of mixing.

Pumped blenders (Figure 4.3) have also been used for mixing in coagulation facilities. In this system, the coagulant is added directly to the water being treated through a diffuser in a pipe. This system can provide rapid dispersion of the coagulant and does not create any significant *HEAD LOSS*[10] in the system. Electrical energy consumption is considerably less than that of a comparable mechanical mixer.

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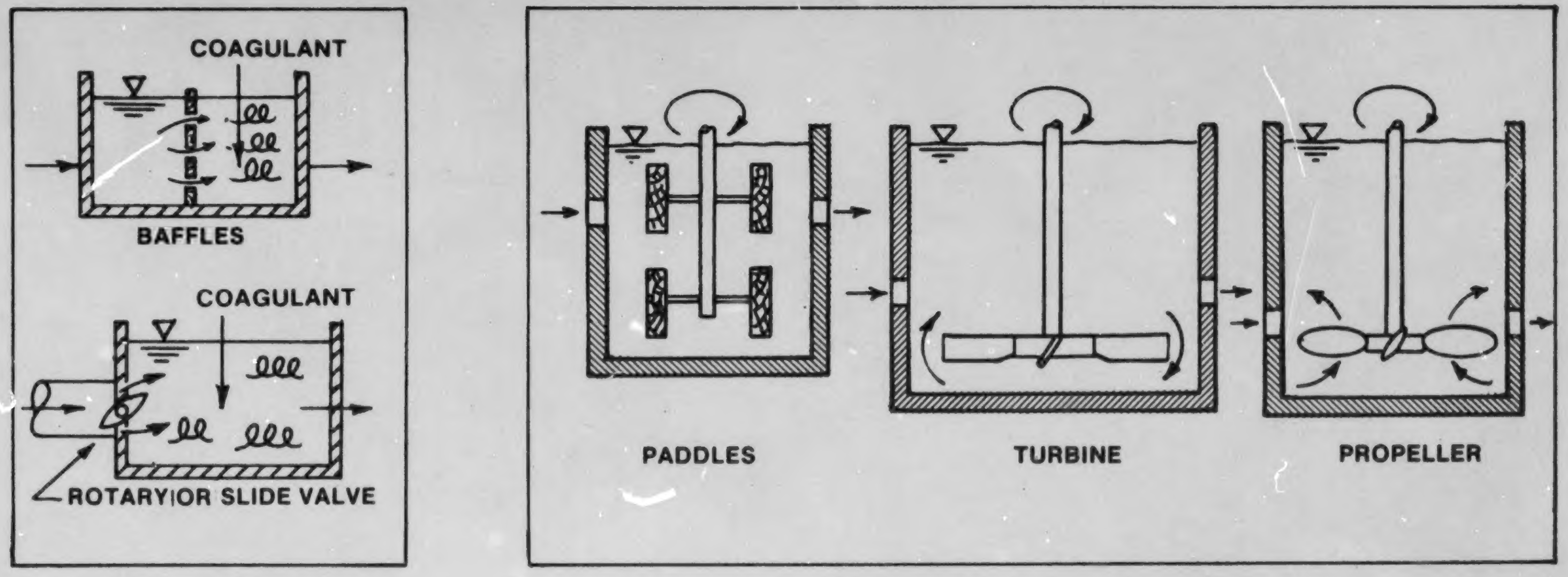
[7] *Alkalinity (AL-ka-LIN-it-tee). The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.*

[8] *Buffer. A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.*

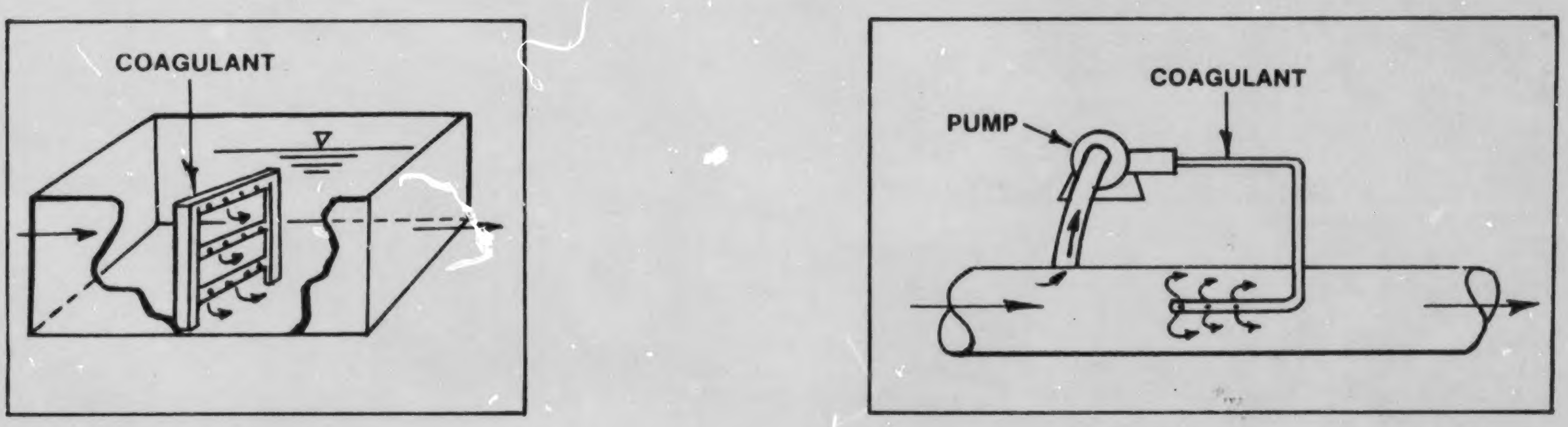
[9] *Jar Test. A laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with differing chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to ESTIMATE the minimum or ideal coagulant dose required to achieve certain water quality goals.*

[10] *Head Loss. The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as result of friction losses.*


COAGULANT
BAFFLES
COAGULANT
ROTARY OR SLIDE VALVE
PADDLES
TURBINE
PROPELLER

HYDRAULIC
(ℓℓℓ – DENOTES TURBULENCE)

MECHANICAL MIXERS
(INSTALLED IN MIXING BASINS)


COAGULANT
COAGULANT
PUMP

DIFFUSER

PUMPED BLENDER
(SEE FIGURE 4.3)

Fig. 4.2 Methods of flash mixing.

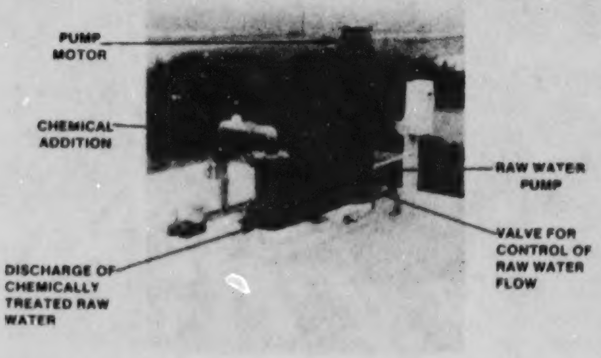

PUMP MOTOR
CHEMICAL ADDITION
RAW WATER PUMP
VALVE FOR CONTROL OF RAW WATER FLOW
DISCHARGE OF CHEMICALLY TREATED RAW WATER

Fig. 4.3 Pump used in pumped blender system

4.232 Coagulation Basins

Mixing of the chemical coagulant can be satisfactorily accomplished in a special rectangular tank with mixing devices. Mixing may also occur in the influent channel or a pipeline to the flocculation basin if the flow velocity is high enough to produce the necessary turbulence. The shape of the basin is part of the flash-mix system design.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 133.

4.2A What is the primary purpose of flash mixing?

4.2B Why are both primary coagulants and coagulant aids used in the coagulation process?

4.2C List four methods of mixing coagulant chemicals into the plant flow.

4.2D What is a hydraulic mixing device?

4.3 FLOCCULATION

4.30 Process Description

Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger, settleable particles. The flocculation process provides contact between particles to promote their gathering together into floc for ease of removal by sedimentation and filtration. Generally, these contacts or collisions between particles result from gentle stirring created by a mechanical or hydraulic means of mixing.

4.31 Floc Formation

Floc formation is controlled by the rate at which collisions occur between particles and by the effectiveness of these collisions in promoting attachment between particles. The purpose of flocculation is to create a floc of a good size, density, and toughness for later removal in the sedimentation and filtration processes. The best floc size ranges from 0.1 mm to about 3 mm, depending on the type of removal processes used (direct filtration vs. conventional filtration which is discussed in Chapter 6, "Filtration").

4.32 Process Performance Considerations

An efficient flocculation process involves the selection of the right stirring time (detention time), the proper stirring intensity, a properly shaped basin for uniform mixing, and mechanical equipment or other means of creating the stirring action. Insufficient mixing will result in ineffective collisions and poor floc formation. Excessive mixing may tear apart the flocculated particles after they have clumped together.

4.320 Detention Time

Detention time is usually not a critical factor in the coagulation or flash-mixing process, if the chemical coagulants are satisfactorily dispersed into the water being treated and mixed for at least several seconds. Detention time is required for the necessary chemical reactions to take place. Some operators have been able to reduce coagulant dosages by increasing the amount of detention time between the point of addition of the coagulant and the flocculation basins. In the flocculation process, however, stirring (detention) time is *QUITE* important. The minimum detention time recommended for flocculation ranges from about 5 to 20 minutes for direct filtration systems and up to 30 minutes for conventional filtration. (The size and shape of the flocculation facility also influences the detention time needed for optimum floc development.)

4.321 Types of Flocculators (Stirrers)

Two types of mechanical flocculators are commonly installed, horizontal paddle wheel types and vertical flocculators (see Figures 4.4 and 4.5). Both types can provide satisfactory performance; however, the vertical flocculators usually require less maintenance since they eliminate submerged bearings and packings. Vertical flocculators can be of the propeller, paddle, or turbine types.

Some flocculation can also be accomplished by the turbulence resulting from the roughness in conduits or channels, or by the dissipated energy of head losses associated with weirs, baffles, and orifices.[11] Generally, these methods find only limited use owing to disadvantages such as very localized distribution of turbulence, inadequate detention time, and widely variable turbulence resulting from flow fluctuations.

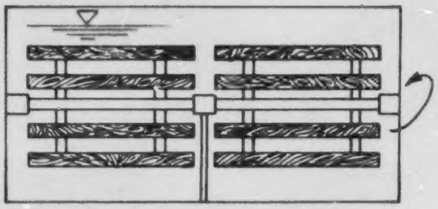
4.322 Flocculation Basins

The actual shape of flocculation basins is determined partially by the flocculator selected, but also for compatibility with adjoining structures (sedimentation basins). Flocculation basins for horizontal flocculators are generally rectangular in shape, while basins for vertical flocculators are nearly square. The depth of flocculation basins is usually about the same as the sedimentation basins.

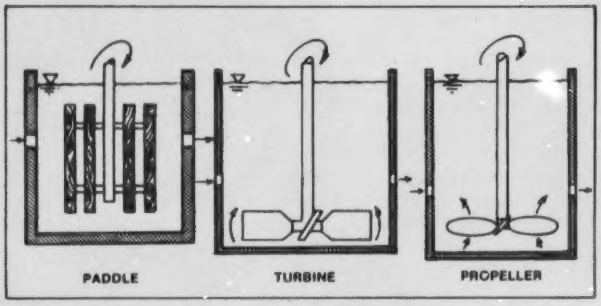
The best flocculation is usually achieved in more than one (most often three) compartmentalized basin rather than one equivalent-sized basin. The compartments are separated by

---

[11] ***Weirs, baffles, and orifices** are flow regulating devices used in flocculation processes to create turbulence which will mix chemicals with the water. Weirs and baffles are boards or plates that water flows over while orifices are holes in walls that water flows through.*



HORIZONTAL PADDLE WHEEL



VERTICAL FLOCCULATORS
(INSTALLED IN FLOCCULATION BASINS)

Fig. 4.4 Types of mechanical flocculations (there are other types)

baffles to prevent *SHORT-CIRCUITING*[12] of the water being treated, and to reduce the level of turbulence in each succeeding compartment by reducing the speed of the stirrers, as shown in Figure 4.6, or reducing the area of the paddles. This is called tapered-energy mixing. The reason for reducing the speed of the stirrers is to prevent breaking apart the large floc particles which have already formed. If you break up the floc you have not accomplished anything and will overload the filters.

The solids-contact process (upflow clarifiers) is used in some water treatment plants to improve the overall solids removal process. These units combine the coagulation, flocculation, and sedimentation processes into a single basin. A detailed discussion of solids-contact units is given in Chapter, 5, *SEDIMENTATION*, Section 5.24, "Solids-Contact Clarification."

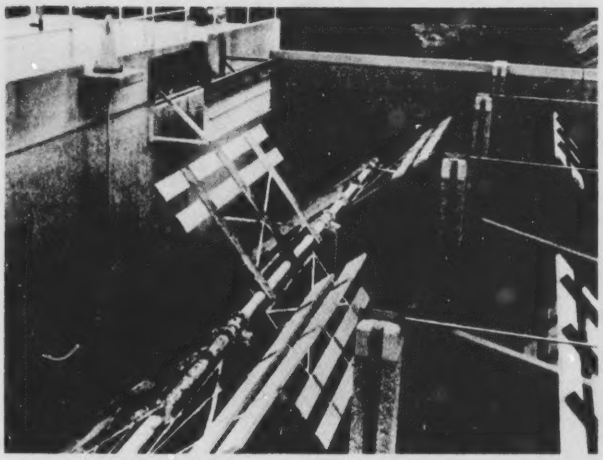


Fig. 4.5 Horizontal paddle wheel flocculator

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 133.

4.3A What is flocculation?

4.3B How long is the typical mixing time in the coagulation process?

4.3C What is the recommended minimum detention time for flocculation?

4.3D What is an advantage of vertical flocculators over horizontal flocculators?

4.3E Why are the compartments in flocculation basins separated by baffles?

4.4 INTERACTION WITH OTHER TREATMENT PROCESSES

In previous sections, the need for coagulation and flocculation was discussed. As you've seen, these processes are required to *PRECONDITION* or prepare nonsettleable particles present in the raw water for removal by sedimentation and filtration. Small particles, without proper coagulation and flocculation, are too light to settle out and will not be large enough to be trapped during filtration. In this regard, it is convenient to consider coagulation-flocculation as one treatment process.

Since the purpose of coagulation-flocculation is to promote particulate removal, the effectiveness of the sedimentation and filtration processes, as well as overall plant performance, depends upon successful coagulation-flocculation. Disinfection of the water can also be affected by poor coagulation-flocculation performance. Bacteria and other disease-causing organisms can be bound up in suspended particles and thereby shielded from disinfection if the solids removal processes before final disinfection, especially filtration, are ineffective. Effective coagulation-flocculation pro-

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[12] *Short-Circuiting. A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.*

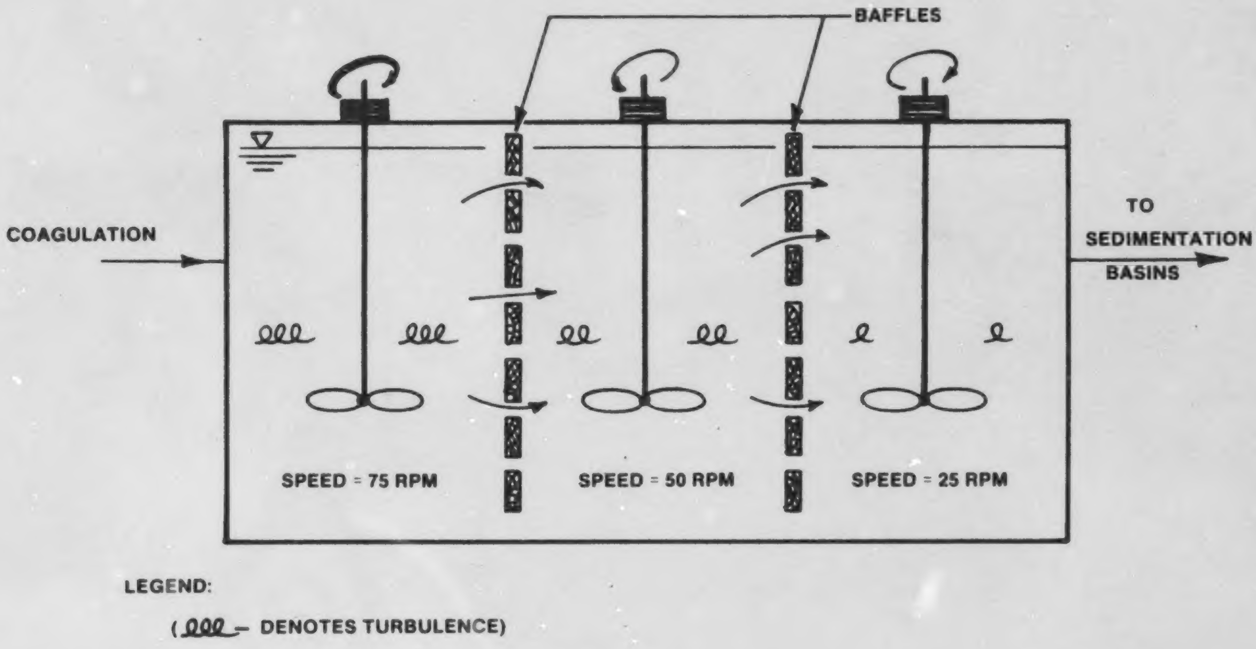

BAFFLES
COAGULATION
TO
SEDIMENTATION
BASINS
SPEED = 75 RPM
SPEED = 50 RPM
SPEED = 25 RPM
LEGEND:
(ℓℓℓ – DENOTES TURBULENCE)

Fig. 4.6 Typical flocculation basin

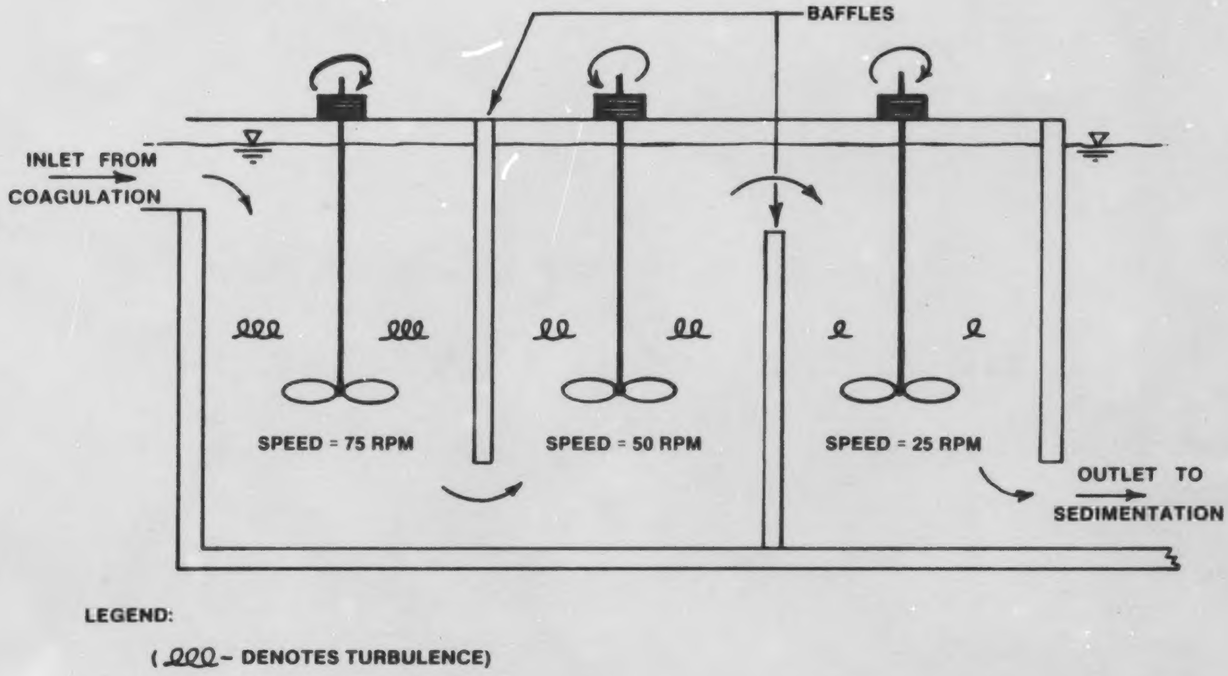
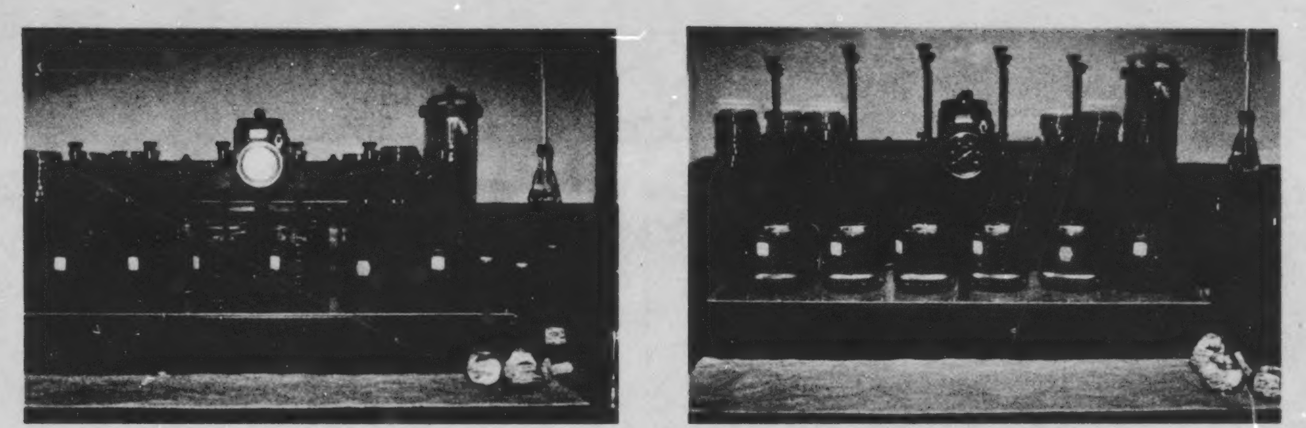

BAFFLES
INLET FROM
COAGULATION
SPEED = 75 RPM
SPEED = 50 RPM
SPEED = 25 RPM
OUTLET TO
SEDIMENTATION
LEGEND:
(ℓℓℓ – DENOTES TURBULENCE)

Fig. 4.6 Typical flocculation basin (Alternate baffle arrangement)



Start of test

End of test (after settling)

Fig. 4.7 Jar test apparatus with mechanical stirrers

motes the removal of natural organic compounds. Removal of these compounds will reduce the formation of trihalomethanes following the use of chlorine for disinfection.

4.5 PROCESS CONTROL

In theory, the chemical reactions and the formation of floc associated with the coagulation-flocculation process are rather complex. Yet from a practical viewpoint, the operator of a water treatment plant must be able to measure and control the performance of these processes on a day-to-day basis.

The most important consideration in coagulation-flocculation process control is selection of the proper type and amount of coagulant chemical(s) to be added to the water being treated. This determination is commonly made in the laboratory with the aid of a jar testing apparatus (Figure 4.7). When selecting a particular type of coagulant chemical, consideration must be given to the quantity and solids content of the sludge created and the means of ultimate disposal. Jar tests should be run at least daily and more often when the quality of the raw water changes. Changes in the raw water may require changes in the amount of chemical and/or type of chemical.

Procedures for determining proper coagulant dosage, as well as means for measuring and controlling coagulation-flocculation process performance are described in the following sections.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 133.

4.4A Why is coagulation-flocculation important to other treatment processes?

4.5A What is the most important consideration in coagulation-flocculation process control?

End of Lesson 1 of 3 Lessons
on
Coagulation and Flocculation

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. COAGULATION AND FLOCCULATION

(Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions which you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. What is the difference between the coagulation and flocculation processes?
2. What is the difference between primary coagulants and coagulant aids?
3. Why have pump blenders become more popular for mixing coagulant chemicals in recent years?
4. What is the purpose of the flocculation process?
5. How does the coagulation-flocculation process affect other treatment processes?
6. How is the proper type and amount of coagulant chemical(s) determined?

Chapter 4. COAGULATION AND FLOCCULATION

(Lesson 2 of 3 Lessons)

4.6 OPERATING PROCEDURES ASSOCIATED WITH NORMAL PROCESS CONDITIONS

4.60 Indicators of Normal Operating Conditions

Coagulation-flocculation is a *PRETREATMENT* process for the sedimentation and filtration processes. Most of the suspended solids are removed in the sedimentation basins and filtration is the final step in the solids removal process. Thus, the coagulation-flocculation process should be operated and controlled to improve filtration and thus produce a filtered water which is low in turbidity.

The measurement of filtered water turbidity on either a periodic (*GRAB SAMPLE*[13]) or continuous basis by a *TURBIDIMETER*[14] will give the operator a good indication of overall process performance. However, the operator cannot rely solely on filtered water turbidity for complete process control. The difficulty in relying on a single water quality indicator such as filtered water turbidity is that it takes a considerable amount of time to transport the water through the various treatment processes. Depending on the amount of water being processed, the total transit time through the treatment plant can vary from 2 to 6 hours or more. This means that a change in coagulant dosage at the front-end of the plant will not be noticed in the final finished water quality for a period of 2 to 6 hours or more, depending on flow conditions. Thus, turbidity as well as other water quality indicators such as pH, temperature, chlorine demand, and floc quality must be monitored throughout the water treatment process. Poor process performance can be spotted early and corrective measures can be taken.

Process control guidelines for a specific plant are often developed to assist the operator in making these determinations. These guidelines are partially based on theory and partially based on experience, but also must be combined with practical knowledge of the source water conditions as well as known performance characteristics of the treatment facilities used for a variety of different treatment conditions.

4.61 Process Actions

In the normal operation of the coagulation-flocculation process, the operator performs a variety of jobs within the water treatment plant. The number and type of functions that each operator will perform varies considerably depending on the size and type of plant and the number of people working in the plant. In smaller plants, the operator is required to control almost all process actions as well as perform most routine maintenance activities. Regardless of the plant size, *ALL* operators should be thoroughly familiar with the routine and special operations and maintenance procedures associated with each treatment process.

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[13] *Grab Sample. A single sample collected at a particular time and place which represents the composition of the water only at that time and place.*

[14] *Turbidimeter. An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.*

Typical jobs performed by an operator in the normal operation of the coagulation-flocculation process include the following:

1. Monitor process performance,
2. Evaluate water quality conditions (raw and treated water),
3. Check and adjust process controls and equipment, and
4. Visually inspect facilities.

Monitoring process performance is an on-going activity. As discussed in Section 4.60, filtered water turbidity levels are controlled to a great extent by the efficiency of the coagulation-flocculation process. Early detection of a pretreatment failure is extremely important because considerable time elapses while the water flows through the coagulation, flocculation, sedimentation and filtration processes.

Process performance can be monitored with the aid of continuous water quality analyzers which automatically measure a specific water quality indicator such as turbidity. However, reliable and accurate water quality analyzers are expensive and, in certain cases, automated equipment is not readily available for measuring all water quality indicators of concern to the operator. Thus, a combination of techniques must be used by the operator to evaluate process performance including visual observations and periodic laboratory tests to supplement any continuous water quality monitors.

Visual observations and laboratory tests of coagulation-flocculation process performance should be performed on a routine basis. The most common laboratory tests are turbidity, alkalinity, pH, color, temperature, and chlorine demand. The frequency of these observations and tests depends on how much the water quality of the water supply source can or does change. In treatment plants where the source water is stored in a large upstream lake or reservoir, the water quality is generally more stable or constant than water taken directly from rivers or streams.

In the case of direct *DIVERSIONS*[15] from a stream or river, water quality conditions will vary seasonally as well as daily. In extreme cases (during heavy runoff periods) even hourly changes in source water quality can be expected. Thus, the appropriate frequency of performing certain tests may be as often as hourly, or perhaps only once per eight-hour shift.

Visual checks of the coagulation-flocculation process generally include an observation of the turbulence of the water in the flash-mixing channel or chamber (you can see improper flow patterns), and close observance of the size and distribution of floc in the flocculation basins. An uneven distribution of floc could be an indication of short-circuiting in the flocculation basin. Floc particles which are too small or too large may not settle properly and could cause trouble during removal in the following processes. These observations are frequently supplemented by laboratory evaluations which are necessary to provide better data. For example, floc settling characteristics require laboratory evaluation, based upon trial and experience methods using the jar test.

Speed adjustment of flocculators, if such a feature is provided, should take into account the following items:

1. Volume of floc to be formed. If source water turbidity is low, a small pinpoint floc may be best suited for removal on the filters (direct filtration). Lower flocculator speeds are appropriate here. On the other hand, high turbidity source waters generally require near-maximum flocculator speed to produce a readily settleable floc.
2. Visual observations. Short-circuiting may indicate flocculator mixing intensity is not sufficient, while floc breakup is an indication that the mixing turbulence (speed) may be too high for the type of floc formed (large alum floc).
3. Water temperature. Lower water temperature[16] requires higher mixing turbulence, so speed should be increased.

Unfortunately, these concepts are not easily measured. Experience and judgment are needed. One of the real limitations in process control is too much reliance on the settled turbidity value. While turbidity gives an indirect measurement of suspended solids concentration, it does not describe particle size, density, volume, nor the ability of a particular filter to handle the applied waters.

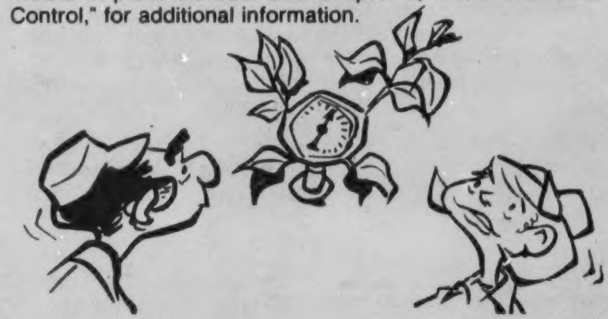
Typical coagulation-flocculation monitoring locations are shown in Figure 4.8. Water quality indicators used to evaluate coagulant dosage and process performance include turbidity, temperature, alkalinity, pH, color, and chlorine demand. These water quality indicators are further discussed in Section 4.9, "Laboratory Tests."

Based upon an overall evaluation of process performance, the operator may need to make minor changes in chemical feed dosages, or adjust the speed of the flash mixer or flocculators, if variable-speed units are provided. These are normal actions associated with minor changes in source water quality such as turbidity or temperature fluctuations.

Flash mixers are generally less sensitive to speed adjustments than flocculators since their primary purpose is to disperse the chemicals rapidly into the water being treated. This reaction is almost instantaneous in such small quantities.

Process equipment such as chemical feeders should be checked regularly to assure that they are accurately feeding the desired amount (feed rate) of chemical. Operation and maintenance of process equipment is discussed in more detail in Section 4.10, "Process and Support Equipment Operation and Maintenance."

The operator should routinely perform a visual inspection of the overall coagulation-flocculation physical facilities. This is a part of good housekeeping practice. Leaves, twigs, and other debris can easily build up in the influent channel or in the flocculation basins. If ignored, this material may get into other processes where it can foul meters, water quality monitors, pumps or other mechanical equipment. In some cases taste and odor problems can develop from microorganisms that can grow in debris and sediment which accumulate in plant facilities. See Chapter 9, "Taste and Odor Control," for additional information.



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[15] *Diversion. Use of part of a stream flow as a water supply.*

[16] *The rate of all chemical reactions decreases with temperature. For example, 50°F (10°C) water slows down chemical reaction times to one-half their speed at 70°F (21°C).*

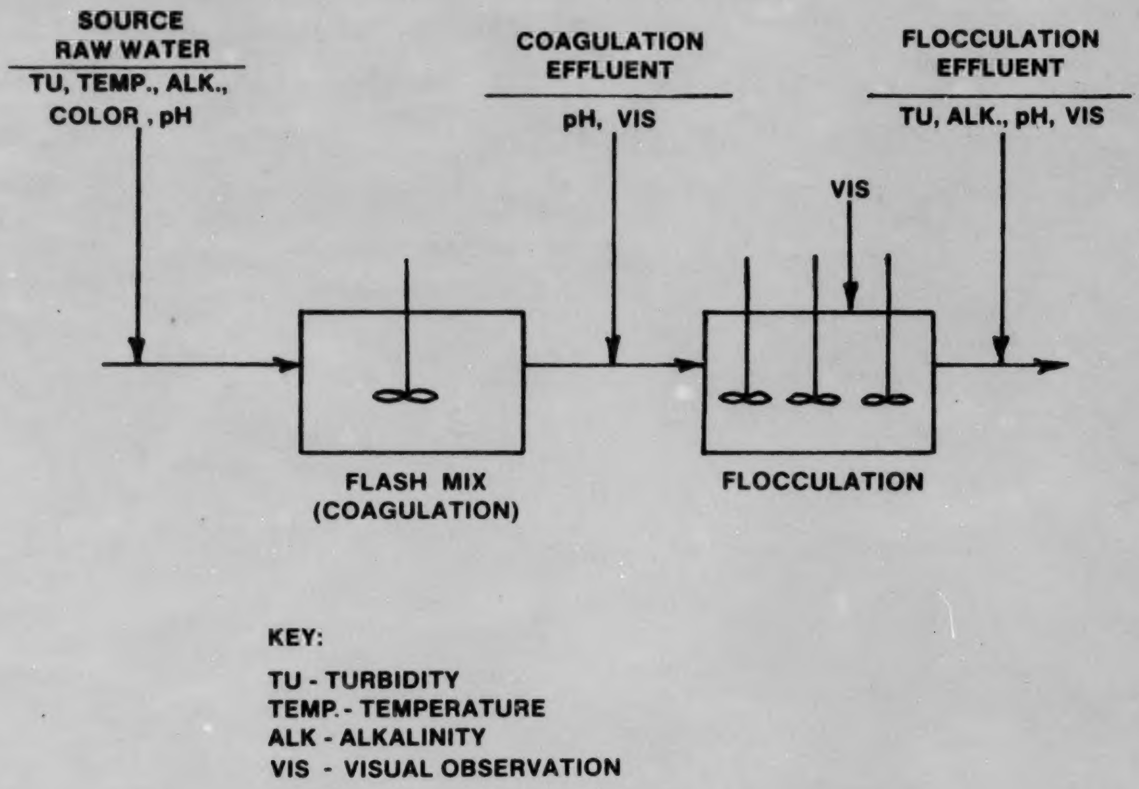

Fig. 4.8 Coagulation-flocculation process monitoring guidelines and sample points

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 133 and 134.

4.6A Which processes remove suspended solids after the coagulation-flocculation process?

4.6B How is the effectiveness of the solids removal processes commonly monitored?

4.6C List the typical functions performed by an operator in the normal operation of the coagulation-flocculation process.

4.6D Which laboratory tests would you use to monitor the coagulation-flocculation process?

4.6E How would you visually observe the performance of a coagulation-flocculation process?

4.62 Process Operation

4.620 Need for Experimentation

In order to illustrate how to operate the actual coagulation-flocculation process, the procedures used in a typical plant will be followed on a step-by-step basis. You must realize that there are many plants that are different from our typical plant and that many waters behave differently than the water being treated here. In actual practice, you will have to experiment with your plant and with your water, but these guidelines may be very helpful to you.

4.621 Physical Facilities

Figure 4.9 shows the overall *PLAN VIEW*[17] of the coagulation-flocculation processes in our typical plant. Chemicals are added to the source water in the flash-mix chamber and mixed by the flash mixer. The water flows from the flash mixer through a distribution channel to the flocculation basins. From the flocculation basins the water flows to the sedimentation basins (Chapter 5) and then to the filters (Chapter 6). From the treatment plant design drawings ("blue prints"), the dimensions (length, width and depth) of the facilities can be determined.

4.622 Detention Times[18]

With the information obtained from the design drawings, we can calculate the expected detention times in the flash-mix chamber, distribution channel, and flocculation basins. These times are important when determining the optimum (best minimum) chemical dosage for the water you are treating by using the jar test. Also these times are necessary for the desired chemical reactions to occur.

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[17] *Plan View. A diagram or photo showing a facility as it would appear when looking down on the top of it.*

[18] *Detention Time. (1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow. (2) The actual time in hours, minutes or seconds a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber.*

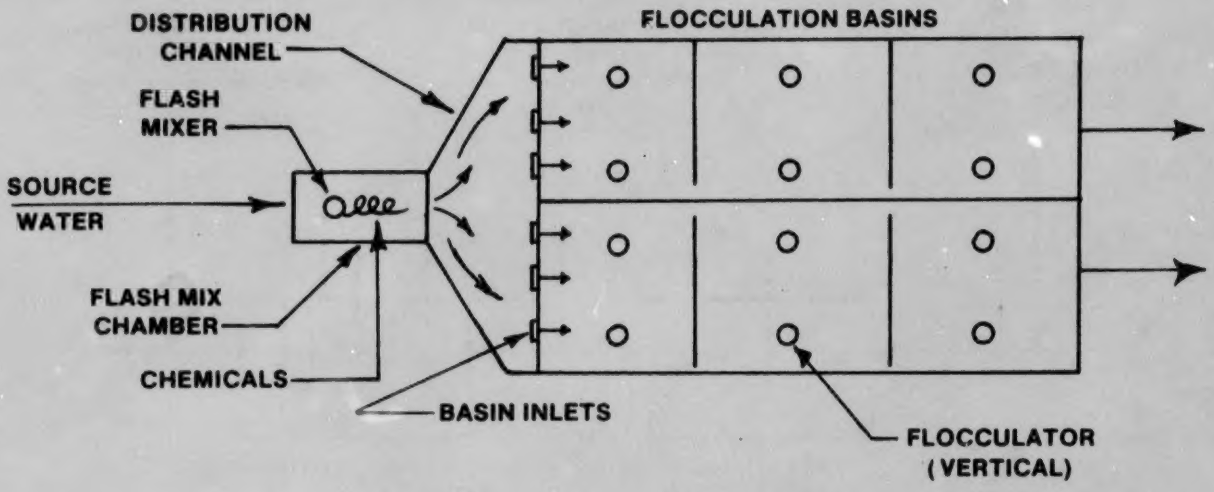

Fig. 4.9 Overall plan view of a typical coagulation-flocculation process

FORMULAS

In order to calculate the detention times of tanks, basins or clarifiers, we must know the volume of the container.

1. To calculate the volume of a rectangular tank or basin in cubic feet,

   Volume, cu ft = (Length, ft)(Width, ft)(Depth, ft)

2. To calculate the volume of a circular tank or clarifier in cubic feet,

   $$\text{Volume, cu ft} = \frac{(\pi)}{4}(\text{Diameter, ft})^2(\text{Depth})$$

   The term $\pi/4$ is equal to 0.785, so this term is commonly used.

   $$\text{Volume, cu ft} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})$$

3. Frequently, we need the volume in gallons, rather than cubic feet.

   Volume, gal = (Volume, cu ft)(7.48 gal/cu ft)

4. To calculate the detention time of any chamber, tank, basin or clarifier,

   $$\text{Detention Time, minutes} = \frac{(\text{Volume, gal})(24\text{ hr/day})(60\text{ min/hr})}{(\text{Flow, gal/day})}$$

   or

   $$\text{Detention Time, hours} = \frac{(\text{Volume, gal})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

Detention times are determined by dividing the volume in gallons by the flow in gallons per day. This will give us the detention time in days. We multiply by 24 hours per day to obtain the detention time in hours. If we wish to convert the detention time from hours to minutes, we multiply by 60 minutes per hour.

EXAMPLE 1

A water treatment plant treats a flow of 2.4 MGD or 2,400,000 gallons per day. The flash-mix chamber is 2.5 feet square (length and width are both 2.5 feet) and the depth of water is 3 feet. Calculate the detention time in seconds.

Known			Unknown
Length, ft	=	2.5 ft	Detention Time, sec
Width, ft	=	2.5 ft	
Depth, ft	=	3.0 ft	
Flow, GPD	=	2,400,000 GPD	

1. Determine the volume of the flash-mix chamber in cubic feet.

   $$\begin{aligned}\text{Volume, cu ft} &= (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})\\ &= (2.5\text{ ft})(2.5\text{ ft})(3.0\text{ ft})\\ &= 18.75\text{ cu ft}\end{aligned}$$

2. Convert the volume of the flash-mix chamber from cubic feet to gallons.

   $$\begin{aligned}\text{Volume, gal} &= (\text{Volume, cu ft})(7.48\text{ gal/cu ft})\\ &= (18.75\text{ cu ft})(7.48\text{ gal/cu ft})\\ &= 140.25\text{ gallons}\end{aligned}$$

3. Calculate the detention time of the flash-mix chamber in seconds.

   $$\begin{aligned}\text{Detention Time, sec} &= \frac{(\text{Volume, gal})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}{\text{Flow, gal/day}}\\ &= \frac{(140.25\text{ gal})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}{2{,}400{,}000\text{ gal/day}}\\ &= 5.0\text{ sec}\end{aligned}$$

EXAMPLE 2

A water treatment plant treats a flow of 2.4 MGD or 2,400,000 gallons per day. The flocculation basin is 8 feet deep, 15 feet wide, and 45 feet long. Calculate the detention time in minutes

Known			Unknown
Flow, GPD	=	2,400,000 GPD	Detention Time, min
Depth, ft	=	8 ft	
Width, ft	=	15 ft	
Length, ft	=	45 ft	

1. Determine the volume of the flocculation basin in cubic feet.

$$\begin{aligned}\text{Volume, cu ft} &= (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})\\ &= (45\ \text{ft})(15\ \text{ft})(8\ \text{ft})\\ &= 5400\ \text{cu ft}\end{aligned}$$

2 Convert the volume of the flocculation basin from cubic feet to gallons.

$$\begin{aligned}\text{Volume, gal} &= (\text{Volume, cu ft})(7.48\ \text{gal/cu ft})\\ &= (5400\ \text{cu ft})(7.48\ \text{gal/cu ft})\\ &= 40{,}392\ \text{gallons}\end{aligned}$$

3. Calculate the detention time of the flocculation basin in minutes.

$$\begin{aligned}\text{Detention Time, minutes} &= \frac{(\text{Volume, gal})(24\ \text{hr/day})(60\ \text{min/hr})}{\text{Flow, gal/day}}\\ &= \frac{(40{,}392\ \text{gal})(24\ \text{hr/day})(60\ \text{min/hr})}{2{,}400{,}000\ \text{gal/day}}\\ &= 24\ \text{minutes}\end{aligned}$$

Many operators prepare curves of flow vs. detention time for the basins in their plant. These curves allow for easy selection of stirring times when performing jar tests. See Appendix A, "Preparation of Detention Time Curves," for detailed procedures.

4.623 The Jar Test

1. Preparation for Test

For a simple, illustrated, step-by-step procedure on how to run a "standard" jar test, see Chapter 11, "Laboratory Procedures, Section 11.3, Water Laboratory Tests, 6, Jar Test." You must realize that it is almost impossible to duplicate in the jar test exactly the flow through conditions that are occurring in your treatment plant. The jar test attempts to duplicate in the laboratory what is occurring in the plant in the relationship to detention times, mixing conditions and settling conditions. By watching the jar test floc form and settle, you can get a good idea of what should happen in your plant for the test chemical dose. The jar test should be used as an indication of what you can expect in your water treatment plant. By closely watching the floc form in the flocculators and settle out in the sedimentation basin of your plant, you can also get a good indication of whether or not you are near the best coagulant dose. Also, by observing the performance of your filters and by looking at the laboratory test results, you will gain additional information that will help you make the necessary adjustments to the actual chemical feed rates. We'll discuss all of these items in more detail in the remainder of this chapter and in the next two chapters (Chapter 5, "Sedimentation," and Chapter 6, "Filtration").

In our typical plant, and thus in the jar test, we are going to use liquid alum as the primary coagulant and a *CATIONIC POLYMER*[19] as a coagulant aid.[20] The size of sample used may be 500 m*L*, 1000 m*L*, or 2000 m*L*. We will use one liter (1000 m*L*) water samples since most "gang stirrers" or jar test apparatus (Figure 4.7) are designed for one liter containers.

Jar test reagents can be prepared at several concentrations depending upon the desired dosage. Table 4.2 lists the most commonly used chemical concentrations for water treatment.

In this example, we will assume the following reagent concentrations are best for our tests:

1. Alum at a 10 mg/*L* solution for each m*L* of stock solution added to one liter of raw water.
2. Cationic polymer at a 1 mg*L* solution for each m*L* of stock solution added to one liter of raw water.

NOTES

1. If you wish to avoid mixing your own chemical reagents for your jar tests, contact your suppliers. Find out from your chemical suppliers the concentrations of chemicals being delivered to your treatment plant. Contact your reagent or laboratory chemical supplier and indicate the strengths of the stock solutions (1,000 mg/*L* or 0.1%) you need to perform the jar tests. There will be a charge for these specially prepared reagents, but the costs are usually considerably less than the value of your time to prepare these reagents. A good practice is to prepare jar test reagents using samples of the chemicals actually used in the plant, rather than reagent grade chemicals. Sometimes trace impurities in industrial chemicals can have significant effects.

Always use fresh reagents.

2. For details on how to prepare fresh reagents, see Chapter 11, "Laboratory Procedures," Section 6, Jar Test, Paragraph 1, Stock Coagulant Solution, (a) Dry alum, and (b) Liquid alum.
3. If you have the laboratory capability, a good practice is to sample new chemical supplies when they are delivered to confirm the quality and strength of the chemical provided.
4. Pages 115 and 116 are typical data sheets used with jar tests. To measure filterability, collect a sample of water from above the settled floc. Pass the water through Whatman No. 40 filter paper and measure the turbidity of the filtered water. Another filterability measurement is to record the time required for 100 m*L* to pass through the filter paper.

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[19] *Cationic Polymer. A polymer having positively charged groups of ions; often used as a coagulant aid.*

[20] *For additional information on the selection and use of coagulant chemicals, see Chapter 10, "Plant Operation."*

TABLE 4.2 DRY CHEMICAL CONCENTRATIONS USED FOR JAR TESTING[a]

Approx. Dosage Required, mg/L[b]	Grams/Liter to Prepare[c]	1 mL Added to 1 Liter Sample Equals	Stock Solution Conc., mg/L (%)
1-10 mg/L	1 gm/L	1 mg/L	1,000 mg/L (0.1%)
10-50 mg/L	10 gm/L	10 mg/L	10,000 mg/L (1.0%)
50-500 mg/L	100 gm/L	100 mg/L	100,000 mg/L (10.0%)

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[a] *From JAR TEST by E.E. Arasmith, Linn-Benton Community College, Albany, Oregon.*

[b] *Use this column which indicates the approximate dosage required by raw water to determine the trial dosages to be used in the jar test.*

[c] *This column indicates the grams of dry chemical that should be used when preparing the stock solution. The stock solution consists of the chemical plus enough water to make a one-liter solution.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 134.

4.6F What is the sequence of solids-removal processes following the flash mixer in the typical treatment plant?

4.6G How do detention times in flash-mix chambers and flocculation basins vary (change) with the flow (MGD or GPM of water being treated)?

4.6H Estimate the detention time (seconds) in a flash-mix chamber 6-feet long, 4-feet wide and 5-feet deep when the rate of flow is 10 MGD.

4.6I How can jar test reagents be obtained?

2. Establish Range of Dosages

Compare your current raw water quality conditions with past records and experiences to determine a range of suitable dosages for the jar tests. Seasonal differences are an important consideration. Laboratory and operations records provide a wealth of information to the operator.

For our typical plant, let's assume that records indicate the proper range of dosages for current water quality conditions are as follows:

Alum:	10 to 20 mg/L
Cationic Polymer:	0.5 to 3 mg/L

3. Establish Test Sequence

Six tests can be run simultaneously on the standard laboratory jar test apparatus (stirring machine). In setting up a multiple-jar series, remember that comparisons between jars that differ in one *ONE* variable (alum dosage, for example) are the most useful. When only one variable is changed and everything else remains the same, any changes in the final outcome will be due to that single variable you changed.

For our typical plant, let's assume that in test sequence No. 1 you decide to evaluate the effect of increasing the polymer dosage while holding the alum dosage constant at 10 mg/L. You will be increasing polymer dosage from 0.5 mg/L to 3 mg/L.

TEST SEQUENCE NO. 1

Jar No.	1	2	3	4	5	6
Alum, mg/L	10	10	10	10	10	10
Cationic Polymer, mg/L	0.5	1.0	1.5	2.0	2.5	3.0

For test sequence No. 2, let's evaluate the effects of varying the polymer dosage at a higher alum dosage (15 mg/L).

TEST SEQUENCE NO. 2

Jar No.	1	2	3	4	5	6
Alum, mg/L	15	15	15	15	15	15
Cationic Polymer, mg/L	0.5	1.0	1.5	2.0	2.5	3.0

Other combinations of alum and cationic polymer may be evaluated by trial and experience to determine the optimum (best possible) dosages. You may wish to try various levels of alum doses first and then try combinations with polymers.

4. Perform Tests

Collect the sample to be tested from the plant flow when you are ready to perform the jar test. The temperature of the water sample being tested should be approximately the same as the temperature of the water being treated. Clear plastic beakers may be used instead of glass beakers because the temperature of the water will change less during the test. However, be sure the plastic beakers are clean before starting the test.

We will use the following jar test procedure:

1. Record test sequence and water quality data;
2. Collect sample;
3. Fill beakers to one-liter mark with water to be tested; and
4. Add measured volumes of chemicals into each beaker (jar) AS QUICKLY AS POSSIBLE. In test sequence No. 1, the following reagent volumes would be added:

STOCKTON-EAST WATER TREATMENT PLANT
JAR TEST

DATE ____/____/____ **TIME** __________ **OPERATOR** __________________

RAW WATER DATA

SOURCE ______________________

TEMP __________ °C **pH** __________

TURBIDITY __________ NTU **COLOR** __________

ALKALINITY __________ mg/l **HARDNESS** __________ mg/l

__________ __________

MIXING SEQUENCE

	RPM	TIME
1.		
2.		
3.		
4.		

		JAR					
CHEMICALS (mg/l)		1	2	3	4	5	6
1. ALUM	LIQUID / DRY						
2.							
3.							
4.							
5.							
6.							
FLOC CHARACTERISTICS	AFTER FLASH MIX						
	AFTER RAPID MIX						
	5 MIN. SLOW MIX						
	10 MIN. SLOW MIX						
	15 MIN. SLOW MIX						
FLOC SETTLING	5 MIN.						
	10 MIN.						
	20 MIN.						
	30 MIN.						
SETTLED WATER QUALITY	TURBIDITY						
	pH						
	COLOR						
	FILTERABILITY						

COMMENTS:

Jar Test Data Sheet

	Flash Mix	Slow Mix	
		1st Stage	2nd Stage
Minutes			
RPM			

Raw Water Characteristics			
Temperature °F	Turbidity JTU	pH	Total Alkalinity mg/l $CaCO_3$

Date

Analyst

Subject

Jar No.	Chemical Used			Floc First Seen Minutes	Floc Characteristics		Settled					Filtered	
					Description Size, nature, etc.	Settling Rate	Temp. °F	Total Alkalinity mg/l $CaCO_3$	Turbidity TU	pH	Color	Turbidity TU	Color
1													
2													
3													
4													
5													
6													

Conclusions:

131

130

Jar No.	1	2	3	4	5	6
Alum Dosage, mg/*L*	10	10	10	10	10	10
Reagent Volume, m*L* (1%)	1	1	1	1	1	1
Cat. Polymer Dosage, mg/*L*	0.5	1	1.5	2	2.5	3
Regeant Volume, m*L* (0.1%)	0.5	1	1.5	2	2.5	3

5. Quickly lower the stirring paddles into the beakers and start them immediately. Operate the paddles for one minute at 80 rpm.

   NOTE: The one minute was based on the detention times in the flash mix and distribution channels with a flow of 3.0 MGD. If the flows were less than 3.0 MGD, we would use more than one minute. Also, if we felt a higher mixing speed (100 rpm) would produce conditions more like actual hydraulic conditions in our plant, we would use a higher mixing speed. Table 4.3 shows the jar mixing times used by one lab and how they are adjusted as the flows change. This lab uses both a flash mix (100 rpm) and a rapid mix (85 rpm). Refer to Appendix A, "Preparation of Detention Time Curves," for procedures on how to prepare a chart similar to Table 4.3 for your plant.

   Settling times cannot be accurately simulated in a one- or two-liter jar test beaker, so these times are shown for information purposes only.

   Adjustment of flash mixer and flocculator speeds in the plant is partly by trial and experience.
6. Reduce mixer speed to 20 rpm for 20 minutes to simulate flocculation basin conditions. If a different speed or mixing time better simulates actual flocculation basin conditions, then we would use these other conditions.
7. Record the time required for visible floc to form and describe the floc characteristics (pin-head sized floc, flake sized floc) during mixing.
8. Stop stirrers. Allow floc to settle for 30 minutes or for a period similar to your plant conditions. Observe and note how quickly the floc settles, floc appearance and turbidity of settled water above the floc. A hazy settled water indicates poor coagulation. Properly coagulated water contains floc particles that are well formed and the water between the particles is clear. Describe the results as poor, fair, good, or excellent.
9. Measure the turbidity of the settled water.
10. Evaluate the results of the jar test.

RESULTS OF TEST SEQUENCE NO. 1

Jar No.	1	2	3	4	5	6
Alum, mg/*L*	10	10	10	10	10	10
Cationic Polymer, mg/*L*	0.5	1.0	1.5	2.0	2.5	3.0
Settled Water Turbidity, TU	0.8	0.4	0.2	0.3	0.5	0.9

Plot the Settled Water Turbidity, TU, vs. Cationic Polymer, mg/*L*, as shown in Figure 4.10. The results indicate that the lowest turbidity was produced by an alum dose of 10 mg/*L* and a cationic polymer dose of 1.5 mg/*L*. Note that when you overdose, the turbidity will increase as shown in Jar Numbers 4, 5 and 6.

TABLE 4.3 JAR TEST MIXING TIMES FOR A WATER TREATMENT PLANT

Plant Flow Rate	Flash Mix Max RPM	Rapid Mix 85 RPM	Slow Mix 40 RPM	Settling Time
(MGD)	(min)	(min)	(min)	(hours)
10	1	23	46.5	4.8
12	1	19.4	38.8	4.0
14	1	16.6	33.3	3.5
15	1	15.5	31.0	3.2
16	1	14.5	29.0	3.0
18	1	13.0	26.0	2.7
20	0.5	11.6	23.3	2.4
22	0.5	10.6	21.0	2.2
24	0.5	9.7	19.4	2.0
26	0.5	9.0	18.0	1.9
28	0.5	8.3	16.6	1.7
30	0.5	7.75	15.5	1.6
35	0.5	6.7	13.3	1.4

Rapid-Mix Basin[a] — 0.16 MG (Total)
Slow-Mix Basin[a] — 0.32 MG (Total)
Sedimentation Basin(s) — 2.01 MG (Total)

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[a] *Flocculation Basins*

NOTE: The volumes in million gallons (MG) and plant flow rates (MGD) are used to calculate the mixing or detention times.

5. Evaluation of Test Results

Several factors are important in evaluating jar test results. These factors include:

1. Rate of floc formation,
2. Type of floc particles,
3. Clarity of water between floc particles,
4. Size of floc,
5. Amount of floc formed,
6. Floc settling rate, and
7. Clarity of water above settled floc.

Visible floc formation should begin shortly after the flash-mix portion of the jar test. During flocculation mixing, a number of small particles will gradually clump together to

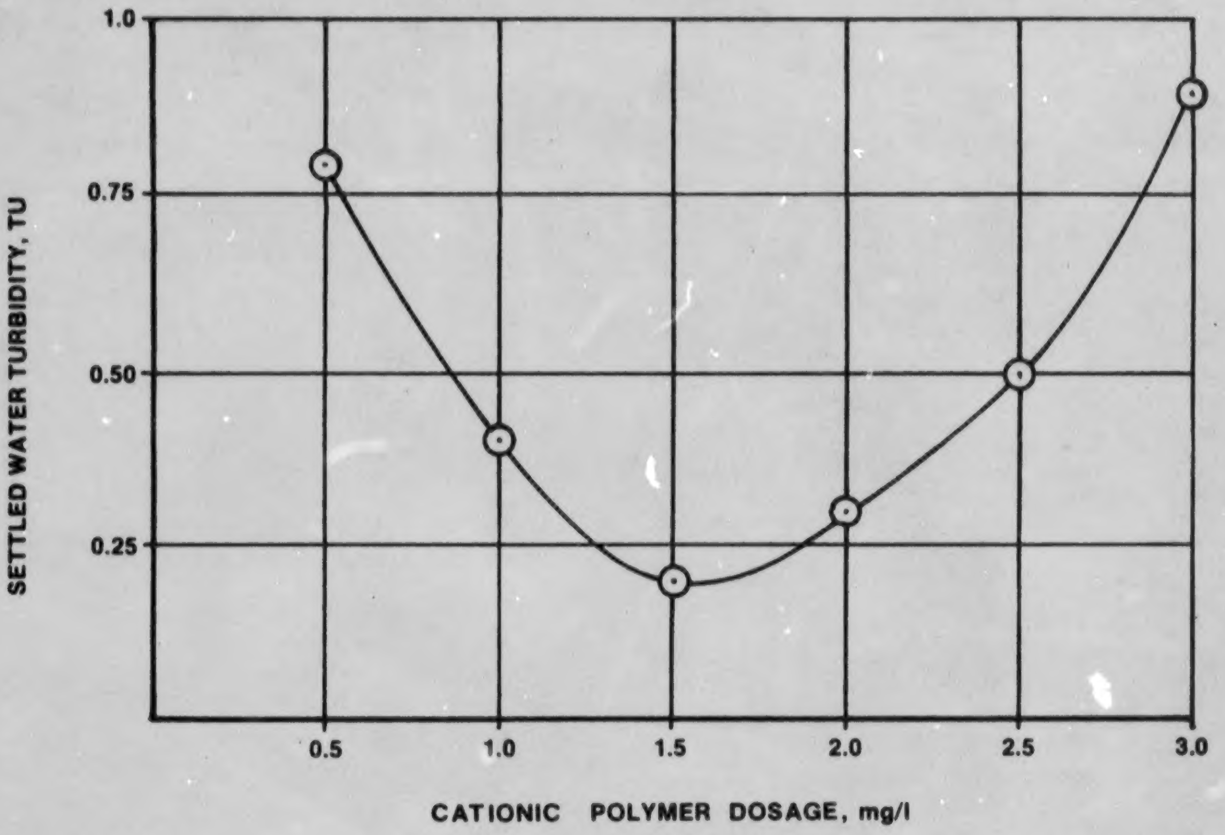

Fig. 4.10 Plot of settled water turbidity vs. cationic polymer dosage

form larger particles. Floc particles that are discrete (separate) and fairly dense in appearance are usually better than floc particles that have a light, fluffy appearance. Large floc is impressive but it is neither necessary nor always desirable. Large, light floc does not settle as well as smaller, denser floc, and it is more subject to shearing (breaking up by paddles and water turbulence).

The quantity of floc formed is not as critical as floc quality or clarity of the settled water produced. The water between the floc particles should be clear and not hazy nor milky in appearance. The best chemical dosage is one which produces a finished water that meets Drinking Water Standards at the lowest cost. Another important consideration is the amount of *SLUDGE*[21] produced. Smaller amounts of sludge are desirable to reduce sludge handling and disposal requirements. Most of the sludge volume consists of precipitates of the added chemicals rather than suspended solids (turbidity) removed.

The rate at which the floc settles after mixing has stopped is another important consideration. The floc should start to settle as soon as the mixer is turned off, and should be almost completely (80 to 90 percent) settled after about 15 minutes. Floc that remains suspended longer than 15 to 20 minutes in the jar test is not likely to settle out in the sedimentation basin, and will increase the load on the filter.

If the floc starts to settle before mixing is completed, or more than about 80 percent of the floc has settled within one or two minutes after mixing has stopped, the floc is too heavy. In your water treatment plant, this can result in the floc settling out in the flocculation basins rather than in the sedimentation basins. (Fortunately this is a rather rare occurrence and indicates that too much chemical has been added.)

6. Frequency of Performing Tests

There is no substitute for experience in evaluating jar test data. Therefore, we recommend that jar tests be performed regularly during periods of high raw water turbidity, even if the plant is producing good quality finished water at the time. This will provide a basis for comparing coagulation-flocculation effectiveness under different conditions and allow "fine-tuning" of the chemical treatment to achieve the best efficiency. Jar tests of flash-mixer water samples (see Section 4.624, "Evaluation of Plant Performance, A., Applying Jar Test Results") should be performed regularly at the start of every shift and more frequently during periods of high turbidity in the raw water. The results of these tests may give an early warning of impending (coming) treatment process problems.

Always *VERIFY* the effectiveness of a change in treatment based upon jar test results. To verify jar test results with treatment plant performance, obtain a water sample just downstream from the flash mixer. Collect the sample after sufficient time has passed for the treatment change to take effect. This sample should be mixed by the jar test apparatus under the same conditions that the original raw water sample was mixed.

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[21] *Sludge (sluj). The settleable solids separated from water during processing. In this case, sediment in the settling basin.*

Jar tests are an effective tool for predicting the results of chemical treatment alternatives. However, jar test results are *USELESS* unless applied and verified in your treatment plant.

4.624 Evaluation of Plant Performance

A. *APPLYING JAR TEST RESULTS*

After evaluation of the jar test results, apply the dosage used to achieve the best jar test results to your water treatment plant operation.

FORMULAS

The settings on chemical feeders will depend on whether you are using a dry chemical feeder or a liquid chemical feeder.

1. Dry chemical feeders are often set on a pounds of chemical fed per day.

$$\text{Feeder Setting, lbs/day} = (\text{Flow, MGD})\ (\text{Alum, mg}/L)(8.34\ \text{lbs/gal})$$

If you change the alum concentration from mg alum per liter of water to pounds of alum per million pounds of water, nothing changes but the units cancel out OK. This is because one liter weighs one million milligrams.

$$\begin{aligned}\text{Feeder Setting, lbs/day} &= (\text{Flow, } \frac{\text{Mil Gal}}{\text{day}})(\text{Alum, } \frac{\text{mg}}{\text{Mil mg}})(8.34\ \frac{\text{lbs}}{\text{gal}})\\ &= (\frac{\text{Mil Gal}}{\text{day}})(\frac{\text{lbs}}{\text{Mil lbs}})(\frac{\text{lbs}}{\text{Gal}})\\ &= \text{lbs/day}\end{aligned}$$

2. Liquid chemical feeders are often set on the basis of milliliters of chemical solution delivered per minute.

$$\text{Chemical Feeder Setting, m}L\text{/min} = \frac{(\text{Flow, MGD})\ (\text{Alum Dose, mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}$$

We have to multiply flow times dosage to get the amount of chemical needed per unit of time. We multiplied by 3.785 *L*/gal to cancel out the gallons in the flow and the liters in the dose. The concentration of liquid alum in mg/m*L* converted the amount of chemical (alum) needed from one amount in milligrams to a volume in milliliters. Since the flow in MGD gave us an amount of chemical needed on a daily basis, we divided by 24 hr/day and 60 min/hr to convert the amount needed to a per minute basis. The 1,000,000 over 1 Million takes care of the Million in MGD.

Liquid alum may be delivered to plants as 8.0 to 8.5 percent Al_2O_3 and contains about 5.36 pounds of dry aluminum sulfate (17 percent dry) per gallon (*SPECIFIC GRAVITY*[22] 1.325). This converts to 642,336 mg/*L*, 642.3 gm/*L* or 642.3 mg/m*L*.

3. To determine a chemical feeder setting in gallons per day (GPD) for a liquid chemical feeder, use the following formula:

$$\text{Chemical Feeder Setting, gal/day} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(8.34\ \text{lbs/gal})}{(\text{Liquid Alum, lbs/gal})}$$

From the first formula in this section, we know that when we multiply flow in MGD times dose in mg/*L* times 8.34 lbs/gal, we get pounds of alum per day. By dividing the pounds of alum in a gallon of liquid alum into this number, we'll get the needed gallons of alum per day.

EXAMPLE 3

The best dry alum dose from the jar tests is 10 mg/*L*. Determine the setting on the alum feeder in pounds per day when the flow is 3.0 MGD.

Known	Unknown
Alum Dose, mg/*L* = 10 mg/*L*	Feeder Setting, lbs/day
Flow, MGD = 3.0 MGD	

Calculate the alum feeder setting in pounds per day.

$$\begin{aligned}\text{Feeder Setting, lbs/day} &= (\text{Flow, MGD})(\text{Alum, mg}/L)(8.34\ \text{lbs/gal})\\ &= (3.0\ \text{MGD})(10\ \text{mg}/L)(8.34\ \text{lbs/gal})\\ &= 250\ \text{lbs/day}\end{aligned}$$

Set the alum feeder to dose alum at a rate of 250 pounds of alum per day.[23] Also set the chemical feeder for the cationic polymer level obtained from the jar test results.

EXAMPLE 4

The optimum liquid alum dose from the jar tests is 10 mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the flow is 3.0 MGD. The liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of liquid solution.

Known	Unknown
Alum Dose, mg/*L* = 10 mg/*L*	Chemical Feeder Setting, m*L*/min
Flow, MGD = 3.0 MGD	
Liquid Alum, mg/m*L* = 642.3 mg/m*L*	

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[22] *Specific Gravity. Weight of a particle, substance, or chemical solution in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Particulates in raw water may have a specific gravity of 1.005 to 2.5.*

[23] *From the 250 lbs/day figure, you may easily calculate the lbs/hr equivalent or whatever other weight/time feed rate for which your equipment is calibrated.*

$$\text{Feeder Setting, lbs/hr} = \frac{250\ \text{lbs/day}}{24\ \text{hr/day}} = 10.4\ \text{lbs/hr}$$

Calculate the liquid alum chemical feeder setting in milliliters per minute.

$$\text{Chemical Feeder Setting, mL/min} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}$$

$$= \frac{(3.0\ \text{MGD})(10\ \text{mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(642.3\ \text{mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}$$

$$= 123\ \text{m}L/\text{min}$$

EXAMPLE 6

The optimum liquid alum dose from the jar tests is 10 mg/*L*. Determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 3.0 MGD. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

Known	Unknown
Alum Dose, mg/*L* = 10 mg/*L*	Chemical Feeder Setting, GPD
Flow, MGD = 3.0 MGD	
Liquid Alum, mg/m*L* = 5.36 lbs/gal	

Calculate the liquid alum chemical feeder setting in gallons per day.

$$\text{Chemical Feeder Setting, GPD} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(8.34\ \text{lbs/gal})}{(\text{Liquid Alum, lbs/gal})}$$

$$= \frac{(3.0\ \text{MGD})(10\ \text{mg}/L)(8.34\ \text{lbs/gal})}{(5.36\ \text{lbs/gal})}$$

$$= 47\ \text{GPD}$$

When the alum and cationic polymer feeders are working properly, collect a sample of well-mixed water from the effluent of the flash-mix chamber to fine-tune process performance. Take the sample to the lab and perform another jar test. First test the alum dosage (is the alum dosage too high or too low?).

1. Add 800 m*L* of sample water to the first jar and 200 m*L* of raw water. Since the chemicals have already been mixed in the sample water, floc will start to form. Be sure the sample stays mixed while pouring off the volumes into the six jars.
2. Add 900 m*L* of sample water to the second jar and 100 m*L* of raw water.
3. Add 1000 m*L* of sample water to the third, fourth, fifth and sixth jars.
4. Add the alum reagent to the fourth, fifth and sixth jars in these amounts:

Jar No.	3	4	5	6
1% Alum Reagent Volume, m*L*	0	0.5	1.0	1.5

5. Mix all six beakers (jars) for one minute at 80 rpm. Adjust time and mixing speed if necessary to simulate plant conditions.
6. Reduce mixer speed to 20 rpm for 20 minutes to simulate flocculation basin conditions.
7. Stop stirrers. Allow floc to settle for 30 minutes. When stirrers are stopped, immediately collect a sample from the flocculation basin effluent. Place 1000 m*L* of this sample in a beaker for comparison with the six beakers used in the jar test.
8. Observe how quickly the floc settles, floc appearance and turbidity of settled water above the floc.
9. Evaluate these jar test results (see Section 4.623, 5, "Evaluation of Test Results"), and make further process adjustments as appropriate.

B. *WALK THROUGH PLANT*

One of the best ways to evaluate the performance of your coagulation-flocculation process is to observe the actual process. When you walk through the treatment plant, take some clear-plastic beakers. Dip some water out of each stage of the treatment process. Hold the sample up to a light and look at the clarity of the water between the floc and study the shape and size of the floc. Study the development of the floc from one flocculation chamber to the next and into the sedimentation basin.

1. Observe the floc as it enters the flocculation basins. The floc should be small and well-dispersed throughout the flow. If not, the flash mixer may not be providing effective mixing or the chemical dose or feed rate may too low.
2. Tiny alum floc may be an indication that the chemical coagulant dose is too low. A "popcorn flake" is a desirable floc appearance. If the water has a milky appearance or a bluish tint, the alum dose is probably too high.
3. What does the floc look like as it moves through the flocculation basins? The size of the floc should be increasing. If the floc size increases and then later starts to break up, the mixing intensity of the downstream flocculators may be too high. Try reducing the speed of these flocculators, or increasing the polymer dosage.
4. Does the floc settle out in the sedimentation basin? If a lot of floc is observed flowing over the *LAUNDERING WEIRS*,[24] the floc is too light for the detention time produced by that flow rate. By increasing the chemical coagulant dose or adding a coagulant aid such as a polymer, a heavier, larger floc may be produced. The appearance of fine floc particles washing over the effluent weirs could be an indication of too much alum and the dose should be reduced. *THEREFORE, REGARDLESS OF YOUR PROBLEM, YOU SHOULD MAKE ONLY ONE CHANGE AT A TIME AND EVALUATE THE RESULTS.* This topic will be discussed more in Chapter 5, "Sedimentation."
5. Bring some beakers with samples from various locations back to the laboratory, let them sit for awhile, and then observe the floc settling.
6. How are the filters performing? This topic will be discussed more in Chapter 6, "Filtration."

C. *VARIATIONS OF THE JAR TEST*

In order to improve the effectiveness of their plant performance and reduce operating costs, many operators continuously experiment to find better ways to do their job. There are many variations and improvements to the "standard" jar test.

1. Some operators have built square jars to use in the jar test because the shape is similar to the actual shape of the flash-mix chamber, flocculation basin and sedimentation tank. The square jars are built by cementing together sheets of clear acrylic plastic. The jars are 11.5 centimeters square and 21 centimeters deep. A water depth of

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[24] ***Laundering Weirs (LAWN-der-ing weer).*** ***Sedimentation basin overflow weir. A plate with V-notches along the top to assure a uniform flow rate and avoid short-circuiting.***

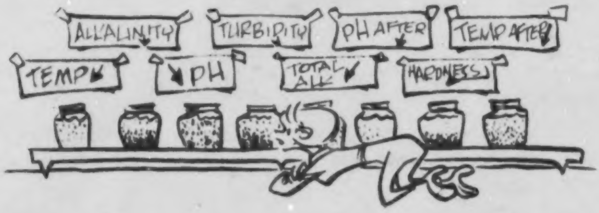
15.2 centimeters represents a two-liter sample. Square jars are also available from laboratory supply houses.

2. Use of Whatman No. 40 filter paper. What really counts is the turbidity of the effluent from your plant filters and the performance of those filters. The settled water above the settled floc in the jars is passed through Whatman No. 40 filter paper and the turbidity of the filtered water measured. Tests with such filter papers have shown that the dosage of coagulant needed to achieve a high quality filtered water may be far below that required to produce a floc that settles well. The lower the chemical dose, the less sludge will be produced. Reducing the chemical dose reduces costs as well.

   Another filterability test is to pass 100 m*L* of water from above the settled floc through the filter paper. Measure the time required for the 100 m*L* sample to pass through the filter paper and record this value as the filterability.

   These tests have also shown that in some cases when a nonsettling floc forms, the flocculators can be shut off without any effect on filtered water turbidity. This could occur when the raw water has a very low turbidity. (For details on these tests, read "Conduct and Uses of Jar Tests," by Herbert E. Hudson, Jr., and E. G. Wagner in Journal of American Water Works Association, Volume 73, No. 4, pages 218-222, April 1981).

3. Additional laboratory tests can be performed to better evaluate the use of coagulants and performance of the processes. Tests that may be conducted on samples before and after jar tests or in the plant at the start and end of the processes include turbidity, temperature, pH, alkalinity, and chlorine demand. Compare these results. You might also want to compare starting and final concentrations of aluminum (if using alum) or iron (if using ferric chloride or ferrous sulfate). The difference in residuals is an indication of the amount of chemicals removed by the processes. Large residuals when the tests are completed indicate chemical overdoses or poor sedimentation and/or filtration efficiencies. These residuals may cause floc to form in the water distribution system.



4. *OPTIMUM pH.* Operators should record the pH during the jar test since some coagulants (especially alum) have an optimum pH range. The pH in the jar after the flash mix that produces the best results becomes a target pH. These operators adjust their chemical feeders to produce the target pH after flash mixing in their treatment plant. This may be an effective means of adjusting chemical feeders for waters with lower alkalinities where pH changes at least a few tenths (7.5 to 7.0) when alum is added.

   Additional jar tests may be run at different pH levels to determine the optimum pH. The chemical dose (alum) could be the same in each jar, but the pH could be changed.

5. *SUMMARY.* Use the procedures that best suit your needs. Only change one operational variable at a time, and wait to analyze the results before changing another variable. Keep good records. Evaluate the performance of your plant and adjust your procedures as necessary.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 134.

4.6J Why should only one variable at a time be changed when running a jar test?

4.6K Why should a jar test sample be collected only when you are ready to perform the jar test and not in advance?

4.6L What factors should be considered when evaluating the results of jar tests?

4.63 Calculating Chemical Doses for Small Plants

This section contains arithmetic problems that the operator of a small treatment plant might be expected to solve. Regardless of the size of your water treatment plant, the procedures for solving these problems are similar.

4.630 Amount of Chemical Required

Operators must be able to estimate the amounts of chemicals used on a monthly basis. Always order enough chemicals in advance so your plant won't run out of needed chemicals.

EXAMPLE 6

A water treatment plant treats an average daily flow of 300,000 GPD. Results from a jar test indicate that the desired polymer dosage for coagulation is 2 mg/*L*. How many pounds of polymer will be used in 30 days?

Known		Unknown
Flow, GPD	= 300,000 GPD = 0.3 MGD	1. Polymer Used, lbs/day 2. Polymer Used, lbs
Polymer Dose, mg/*L*	= 2 mg/*L*	
Time, days	= 30 days	

1. Calculate the polymer used in pounds per day.

Polymer Used, lbs/day = (Flow, MGD)(Dose, mg/*L*)(8.34 lbs/gal)

= (0.3 MGD)(2 mg/*L*)(8.34 lbs/gal)

= 5 lbs/day

2. Estimate the polymer used in 30 days.

Polymer Used, in 30 days = (Polymer Used, lbs/day)(Time, days)

= (5 lbs/day)(30 days)

= 150 lbs

4.361 Chemical Feeding

The chemical feed rate delivered by chemical feeders must be checked regularly. Jar tests will show the best dosages of chemicals in mg/*L*. To check on the actual feed rate delivered by a chemical feeder, you measure the volume (in gallons for a liquid chemical feeder) or the weight (in pounds for a dry chemical feeder) delivered during a 24-hour period. The flow during this time period also needs to be known and is recorded in gallons per day (GPD) or million gallons per day (MGD).

EXAMPLE 7

During a 24-hour period a plant treated a flow of 1.5 million gallons. Ten pounds of cationic polymer were used in the coagulation process. What is the polymer dosage in mg/*L*?

Known		Unknown
Flow, MGD	= 1.5 MGD	Polymer Dose, mg/*L*
Polymer Used, lbs/day	= 10 lbs/day	

1. Calculate the polymer dose in mg/*L*.

The basic equation is

$$\text{Polymer Used, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

Rearrange the equation to

$$\text{Polymer Dose, mg}/L = \frac{\text{Polymer Used, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{10\text{ lbs/day}}{(1.5\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 0.8\text{ mg}/L$$

This actual polymer dose of 0.8 mg/*L* should be very close to the best dose obtained from the jar test. Also walk through your plant and observe how the water you are treating responds to a polymer dose of 0.8 mg/*L*. You hope to see a good settling floc. If the floc is not settling properly, the polymer dose may have to be increased or decreased.

EXAMPLE 8

What is the alum dosage in mg/*L* if a water treatment plant treats a source water with an average flow of 700 GPM and an average turbidity of 10 TU? A total weight of 150 pounds of alum is used during a 24-hour period.

Known		Unknown
Flow, GPM	= 700 GPM	Alum dose, mg/*L*
Alum Used, lbs/day	= 150 lbs/day	

1. Calculate the flow of 700 GPM to MGD.

$$\text{Flow, MGD} = \frac{(\text{Flow, gal/min})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{M}}$$

$$= \frac{(700\text{ gal/min})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000/\text{M}}$$

$$= 1.0\text{ MGD}$$

2. Calculate the alum dose in mg/*L*.

$$\text{Alum Dose, mg}/L = \frac{\text{Alum Used, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{150\text{ lbs/day}}{(1.0\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 18.0\text{ mg}/L$$

NOTE: For an example of how to calculate the lime dosage to provide the alkalinity when using alum, see Chapter 5, Section 5.243, "Arithmetic for Solids-Contact Clarification."

4.532 Preparation of Chemical Solutions

Polymers are frequently used as coagulant aids. Often the operator starts with a dry polymer chemical and wants to prepare a specific solution concentration (as mg/*L* or as a percent solution). The solution concentration depends on the type of polymer (cationic, nonionic, or anionic) and the polymer's molecular weight (this weight may vary from 100 to ten million). The higher the molecular weight of the polymer, the more difficult it is to mix the polymer with dilution water and to feed the resulting solution to the water being treated (the solution becomes very viscous (thick)). Therefore, anionic and nonionic dry polymers used as coagulant aids are often prepared as very dilute (weak) solutions (0.25 to 1.0 percent). Cationic polymers in the dry form can be prepared at higher solution concentrations (say 5 to 10 percent), since their molecular weights are typically small.

High molecular weight polymers are very difficult to prepare. To be effective, polymer solutions must be the same throughout (homogeneous). They must be thin enough to be accurately measured and pumped to the flash-mix chamber.

When mixing a dry polymer with water, sift or spread the polymer evenly over the surface of the water in the mixing chamber. The polymer should be sucked evenly into the hole (vortex) of the stirred water. This will insure that each particle of polymer is wet individually. This will also insure even dispersion and prevent the formation of large, sticky balls of polymer which have dry polymer in the middle.

Excessive mixing speeds, mixing time, and the build up of heat can break down the polymer chain and reduce its effectiveness.

High concentrations of polymer result in very thick, viscous (sticky) solutions. Prepare and use concentrations of polymers which can be metered (measured) easily and pumped accurately to the flash mixer.

The addition of dry polymer to water must be done in a closed system or under an efficient dust collector. Polymer powders on floors and walkways become extremely slippery when wet and are very difficult to remove. In the interest of safety, keep polymers off the floors.

FORMULAS

When mixing either dry or liquid polymers, always follow the directions of the polymer supplier. Polymer solutions are usually prepared in "batches" or as a "batch mixture." Often they are stored after mixing in a "day tank" or an "aging tank" to allow time for the powder to all dissolve and/or the solution to become completely mixed.

DRY POLYMERS

To prepare a specific percent polymer solution use the following formula:

$$\text{Polymer, \%} = \frac{(\text{Dry Polymer, lbs})(100\%)}{(\text{Dry Polymer, lbs} + \text{Water, lbs})}$$

Examination of the above formula reveals three possible unknowns. In addition to wanting to know the percent polymer solution, the operator might wish to know the pounds of dry polymer to use or the amount of water in either pounds or probably gallons to mix with the polymer. In any case, two of the three unknowns must be known to solve the problem. The above basic polymer formula to find the polymer concentration as a percent can be rearranged to solve for the other two unknowns.

$$\text{Dry Polymer, lbs} = \frac{\text{Water, lbs}}{\left(\dfrac{100\%}{\text{Polymer, \%}} - 1.0\right)}$$

$$\text{Water, lbs} = \frac{(\text{Dry Polymer, lbs})(100\%)}{\text{Polymer, \%}} - \text{Dry Polymer, lbs}$$

$$\text{Water, gal} = \frac{\text{Water, lbs}}{(8.34\ \text{lbs/gal})}$$

LIQUID POLYMERS

When working with liquid polymers we usually know the percent polymer in the liquid polymer we receive from the supplier. The problem is to determine how much of the supplier's polymer should be mixed with water to give us a tank or barrel with a diluted or lower percent polymer.

The basic liquid polymer formula is as follows:

$$(\text{Polymer, \%})(\text{Volume, gallons}) = (\text{Polymer, \%})(\text{Volume, gallons})$$

The volume term could also be expressed in liters. Also the basic liquid polymer formula could be rearranged as follows:

$$\text{Polymer, \%} = \frac{(\text{Polymer, \%})(\text{Volume, gallons})}{\text{Volume, gallons}}$$

OR

$$\text{Volume, gallons} = \frac{(\text{Polymer, \%})(\text{Volume, gallons})}{\text{Polymer, \%}}$$

EXAMPLE 9

At the beginning of each shift, or each day, the operator of a small plant mixes a batch of nonionic polymer solution. What is the percent (by weight) polymer solution if the operator adds 60 grams (0.132 pounds) of dry polymer to five gallons of water?

Known	**Unknown**
Dry Polymer, lbs = 0.132 lbs	Polymer Solution, %
Volume Water, gal = 5 gal	

1. Convert the five gallons of water to pounds.

$$\begin{aligned}\text{Water, lbs} &= (\text{Volume Water, gal})(8.34\ \text{lbs/gal})\\ &= (5\ \text{gal})(8.34\ \text{lbs/gal})\\ &= 41.7\ \text{lbs}\end{aligned}$$

2. Calculate the polymer solution as a percent.

$$\begin{aligned}\text{Polymer, \%} &= \frac{(\text{Dry Polymer, lbs})(100\%)}{(\text{Dry Polymer, lbs} + \text{Water, lbs})}\\ &= \frac{(0.132\ \text{lbs})(100\%)}{(0.132\ \text{lbs} + 41.7\ \text{lbs})}\\ &= 0.32\%\end{aligned}$$

EXAMPLE 10

How many pounds of dry polymer must be added to 50 gallons (417 pounds) of water to produce a 0.5 polymer solution?

Known	**Unknown**
Water Volume, gal = 50 gal	Dry Polymer, lbs
Water Weight, lbs = 417 lbs	
Polymer, % = 0.5%	

Calculate the pounds of dry polymer that must be added to 50 gallons of water.

$$\begin{aligned}\text{Dry Polymer, lbs} &= \frac{\text{Water, lbs}}{\left(\dfrac{100\%}{\text{Polymer, \%}} - 1.0\right)}\\ &= \frac{417\ \text{lbs}}{(\dfrac{100\%}{0.5\%} - 1.0}\\ &= \frac{417\ \text{lbs}}{200-1.0}\\ &= 2.1\ \text{lbs}\end{aligned}$$

OR

$$\begin{aligned}&= (2.1\ \text{lbs})(454\ \text{grams/lb})\\ &= 951\ \text{grams}\end{aligned}$$

EXAMPLE 11

How many gallons of water should be mixed with 1.5 pounds of dry polymer to produce a 0.5 percent polymer solution?

Known	**Unknown**
Polymer, % = 0.5%	Water, gallons
Dry Polymer, lbs = 1.5 lbs	

1. Calculate the pounds of water needed.

$$\begin{aligned}\text{Water lbs} &= \frac{(\text{Dry Polymer, lbs})(100\%)}{\text{Polymer, \%}} - \text{Dry Polymer, lbs}\\ &= \frac{(1.5\ \text{lbs})(100\%)}{0.5\%} - 1.5\ \text{lbs}\\ &= 300\ \text{lbs} - 1.5\ \text{lbs}\\ &= 298.5\ \text{lbs}\end{aligned}$$

2. Calculate the volume of water in gallons to be mixed with the polymer.

$$\begin{aligned}\text{Volume Water, gallons} &= \frac{\text{Water, lbs}}{8.34\ \text{lbs/gal}}\\ &= \frac{298.5\ \text{lbs}}{8.34\ \text{lbs/gal}}\\ &= 35.8\ \text{gallons}\end{aligned}$$

EXAMPLE 12

Liquid polymer is supplied to a water treatment plant as a ten percent solution. How many gallons of liquid polymer should be mixed in a barrel with water to produce 50 gallons of 0.5 percent polymer solution?

Known	Unknown
Liquid Polymer, % = 10%	Volume of Liquid Polymer, gal
Polymer Solution, % = 0.5%	
Volume of Polymer Solution, gal = 50 gal	

Calculate the volume of liquid polymer in gallons.

$$\text{Liquid Polymer, gal} = \frac{(\text{Polymer Solution, \%})(\text{Volume of Solution, gal})}{\text{Liquid Polymer, \%}}$$

$$= \frac{(0.5\%)(50 \text{ gal})}{10\%}$$

$$= 2.5 \text{ gallons}$$

NOTE: The volume of the polymer solution is 50 gallons. This means that we have 2.5 gallons of liquid polymer and 47.5 gallons (50-2.5) of water mixed together.

4.64 Recordkeeping

One of the most important *ADMINISTRATIVE* functions of the water treatment plant operator is the preparation and maintenance of accurate plant operation records.

In the routine operation of the coagulation-flocculation process, the operator usually makes entries in and maintains records such as daily operations logs and diaries. These records should provide an accurate day-to-day account of actual operating experience.

HISTORIC DATA
G. WASHINGTON DRANK HERE

Accurate records provide the operator as well as others, with a running account of operations (historical records), and are a great help to the operator in solving current or future process problems. They also provide a factual account of the operation which is required by law and by regulatory agencies.

In the coagulation-flocculation process, you should keep records of the following items:

1. Source water quality (pH, turbidity, temperature, alkalinity, chlorine demand, and color),
2. Process water quality (pH, turbidity and alkalinity),
3. Process production inventories (chemicals used, chemical feed rates, amount of water processed, and amount of chemicals in storage), and
4. Process equipment performance (types of equipment in operation, maintenance procedures performed, equipment calibration and adjustments).

Record entries should be neat, legible, and easily found. Keep in mind that many records will be kept and may be used for long periods of time. Entries should reflect the date and time of an event and should be initialed by the operator making the entry for future identification.

Operators should maintain a plot of key process variables. A plot of source water turbidity vs. coagulant dosage should be maintained. If other process variables such as alkalinity or pH vary significantly, these should also be plotted.

These graphs should be designed so that the operator can see one year of data at one time. This will give the operator a better understanding of the seasonal variation in these water quality indicators. A sample graph showing a plot of source water turbidity vs. alum dosage is given in Figure 4.11.

4.65 Safety Considerations

In the routine operation of the coagulation-flocculation process, the operator will be exposed to a number of potential hazards such as:

1. Electrical equipment,
2. Rotating mechanical equipment,
3. Water treatment chemicals,
4. Laboratory reagents (chemicals),
5. Slippery surfaces caused by wet polymers,
6. Open-surface, water-filled structures (drowning), and
7. Confined spaces and underground structures such as valve or pump vaults (toxic and explosive gases, insufficient oxygen).

You must realize that accidents do not just happen, they are caused. Therefore, strict and constant attention to safety procedures cannot be over-emphasized.

The operator should be familiar with general first aid practices such as mouth-to-mouth resuscitation, treatment of common physical injuries, and first-aid for chemical exposure (chlorine). When you come to Chapter 20, "Safety," please read the material carefully and review the chapter from time to time.

4.66 Communications

Good communications are an essential part of the operator's job. Clear and concise written or oral communications are necessary to advise other operators and support personnel of current process conditions and unique or unusual events. In this regard, good recordkeeping is an essential element of the communication process.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 134.

4.6M Why should operators keep accurate records?

4.6N What information should be recorded for all entries in a record book?

4.6O List the safety hazards an operator may encounter when operating a coagulation-flocculation process.

4.6P Why are good communications such an essential part of an operator's job?

End of Lesson 2 of 3 Lessons on Coagulation and Flocculation

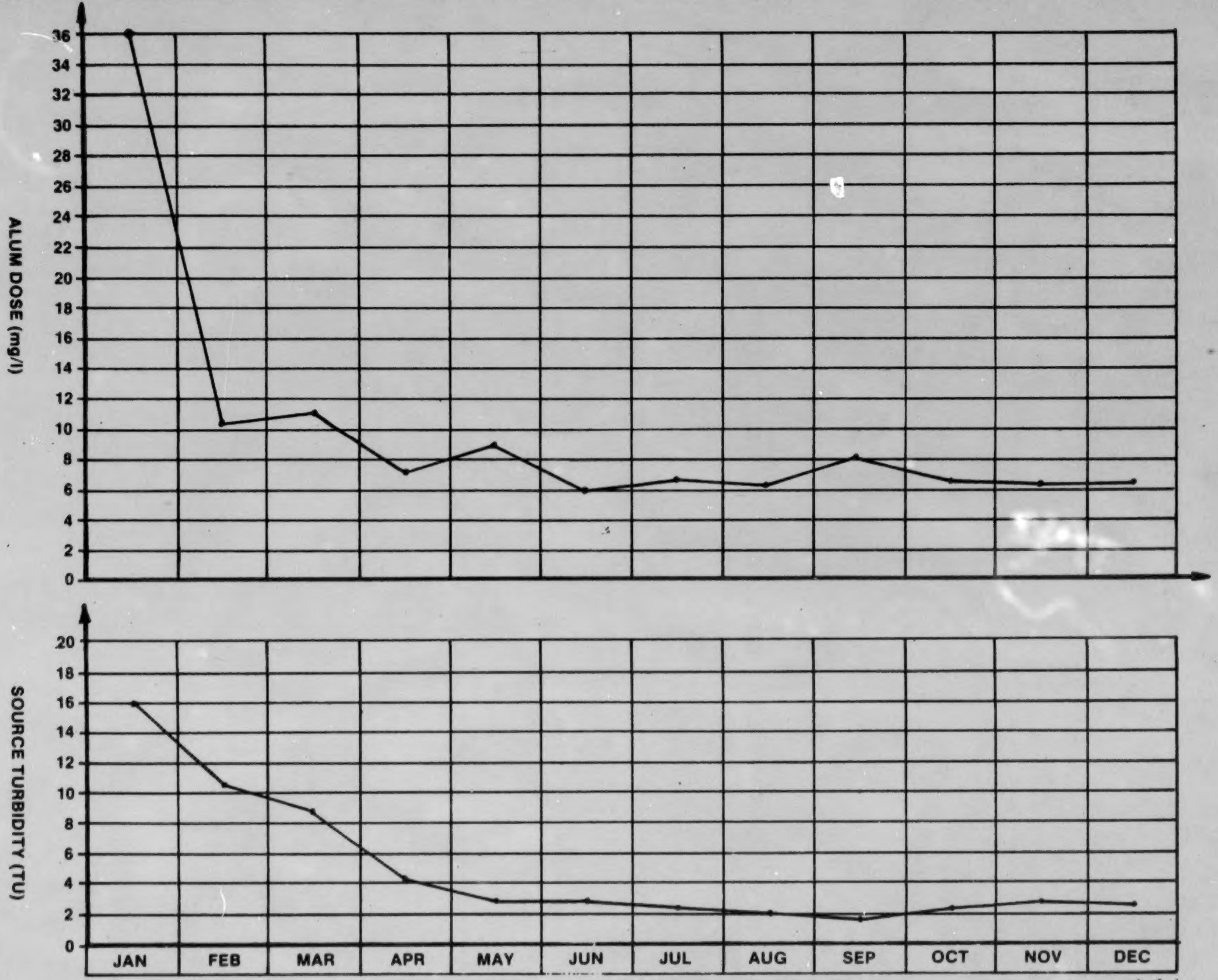


Fig. 4.11 Monthly variations in turbidity and alum dosage

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. COAGULATION AND FLOCCULATION

(Lesson 2 of 3 Lessons)

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 1.

7. Why might the jar test guidelines outlined here (mixing speed, time, dose) not be proper for your water treatment plant?
8. What is the basic purpose of the jar test?
9. Why do some operators use square jars in the jar test?
10. How frequently should jar tests be performed?
11. What are the limitations of relying solely on the turbidity of filtered water as an indication of overall process performance?
12. How often should samples be collected and analyzed when operating a coagulation-flocculation process?
13. How do accurate records help operators?
14. What types of records should be kept when operating a coagulation-flocculation process?
15. How should an operator communicate with other operators?

CHAPTER 4. COAGULATION AND FLOCCULATION

(Lesson 3 of 3 Lessons)

4.7 OPERATING PROCEDURES ASSOCIATED WITH ABNORMAL PROCESS CONDITIONS

4.70 Indicators of Abnormal Conditions

Sudden changes in the source water or filtered water turbidity, pH, alkalinity, temperature, or chlorine demand, are signals that the operator should immediately review the performance of the coagulation-flocculation process.

4.71 Process Actions

Changes in source water turbidity levels, either increases or decreases, generally require that the operator verify the effectiveness of the coagulant chemicals and dosages being applied at the flash mixer. This is best accomplished by performing a series of jar tests in the laboratory as discussed previously. You must realize that decreasing raw water turbidity levels can be just as upsetting to the process as increasing levels.

Visual observations of flash-mixing intensity as well as the condition of the floc in the flocculation basins may also indicate the need for process changes such as adjustment of mixer speed or coagulant dosage.

Alkalinity, pH, and temperature changes in the source water quality may have an impact on the clumping together of floc during the coagulation-flocculation process. In addition, water temperature changes may require an adjustment in the level of mixing intensity in flash mixers or flocculators. Temperature changes are usually gradual over time, thus large process adjustments are seldom necessary.

Sudden increases in filtered water turbidity could be caused by poor filter performance (need for backwashing or replacing filter media). However, poor coagulation-flocculation performance is usually the culprit, and the operator must take immediate action to correct the problem, remembering that several hours may pass before changes in the operation of the coagulation-flocculation process are seen in the filter effluent. One quick remedy may be to feed a filter-aid chemical such as a nonionic polymer, directly to the filter influent. While this may solve the short-term problem, only changes in the coagulation-flocculation process will enhance long-term plant performance. Again, the results of laboratory jar tests should be used as the basis for making process changes. Filter-aid chemicals are discussed further in Chapter 6, "Filtration."

Table 4.3 is a summary of coagulation-flocculation process problems, how to identify the causes of these problems, and also how to go about trying to correct the problems.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 134.

4.7A What kinds of sudden changes in either raw or filtered water quality are signals that you should immediately review the performance of the coagulation-flocculation process?

4.7B What would you do if you observed a significant change in source water turbidity level?

4.7C How could you verify the effectiveness of the type and dosage of coagulant chemicals and dosages being applied at the flash mixer?

4.7D If source water temperature changes suddenly, what changes should an operator consider?

4.72 Recordkeeping

During times of abnormal plant operating conditions, good recordkeeping takes on an added importance, that of documenting the unique conditions or special events and the actions taken by the operator to solve the problem. In addition to the normal log book entry requirements, the operator must also keep accurate notes describing unusual conditions and any steps taken to prevent or resolve prob-

TABLE 4.4 COAGULATION-FLOCCULATION PROCESS TROUBLESHOOTING

Source Water Quality Changes	Operator Actions	Possible Process Changes
• Turbidity • Temperature • Alkalinity • pH • Color	1. Perform necessary analyses to determine extent of change. 2. Evaluate overall process performance. 3. Perform jar tests if indicated. 4. Make appropriate process changes (see right hand column, Possible Process Changes). 5. Increase frequency of process monitoring. 6. Verify response to process changes at appropriate time (be sure to allow sufficient time for change to take effect).	1. Change coagulant(s). 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity.[a] 4. Add coagulant aid or filter aid. 5. Adjust alkalinity or pH.

Coagulation Process Effluent Quality Changes	Operator Actions	Possible Process Changes
• Turbidity • Alkalinity • pH	1. Evaluate source water quality. 2. Perform jar tests if indicated. 3. Verify process performance: (a) Coagulant feed rates(s), (b) Flash mixer operation. 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time.	1. Change coagulant(s). 2. Adjust coagulant dosage. 3. Adjust flash mixer intensity (if possible). 4. Adjust alkalinity or pH.

Flocculation Basin Floc-Quality Changes	Operator Actions	Possible Process Changes
• Floc formation	1. Observe floc condition in basin: (a) Dispersion, (b) Size, and (c) Floc strength (breakup). 2. Evaluate overall process performance. 3. Perform jar tests if indicated: (a) Evaluate floc size, settling rate and strength. (b) Evaluate quality of supernatant; clarity (turbidity), pH, and color. 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Add coagulant aid. 5. Adjust alkalinity or pH.

[a] NOTE: Very few plants have provisions for adjusting the flash mixer. However, many plants have variable-speed drives on flocculators to allow for adjustment of mixing intensity.

lems. Often, a "non-result" following an attempted corrective action is as important as a correct solution to the problem. A "non-result" helps us and others learn from our experience and next time we can try something different. Thus, *ALL* actions should be carefully documented by the operator.

Detailed notes may be useful in the design of future water treatment plant facilities, or in the modification of existing facilities. In addition, records such as these provide a historical account of actions taken by the operator, and may be helpful from a legal or regulatory agency perspective. Special reports may need to be prepared describing the events and actions taken. The operator's notes provide the facts for these reports.

4.73 Communications

During abnormal periods of operation, you may be required to advise other plant personnel such as the Senior Operator, Plant Superintendent, Chemist, or Maintenance Mechanic, of the conditions which exist or events which have occurred.

An *EMERGENCY RESPONSE* procedure should be developed for every water treatment plant so that notification of the proper personnel can be quickly done and the emergency resolved. Emergency response procedures should list the *NAMES AND TELEPHONE NUMBERS* (including off-hours, nights and weekends) of persons to be notified under specific conditions, including health department authorities. Guidelines should be developed to assist the operator in determining when to use these procedures.

Coagulation-flocculation process changes or other conditions which may require notification of others include:

1. Contamination of source water with a chemical spill;
2. Major changes in source or treated water quality (pH, turbidity, alkalinity, and bacteriological quality);
3. Lack of response to changes in coagulant dosage;
4. Equipment failure (chlorinators, chemical feeders, mixers, and pumps); and
5. Power outages.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 134 and 135.

4.7E Why is good recordkeeping especially important during abnormal plant operating conditions?

4.7F During periods of abnormal operating conditions, which laboratory tests may be performed more frequently?

4.7G Why should an emergency response procedure be developed for every water treatment plant?

4.8 STARTUP AND SHUTDOWN PROCEDURES

4.80 Conditions Requiring Implementation of Startup/Shutdown Procedures

Startup or shutdown of the coagulation-flocculation process is *NOT* a routine operating procedure in most water treatment plants. These procedures generally happen when the plant is shutdown for maintenance. In some rare instances, a shutdown may be required due to a major equipment failure.

4.81 Implementation of Startup/Shutdown Procedures

Typical actions performed by the operator in the startup or shutdown of the coagulation-flocculation process are outlined below. These procedures may have to be altered depending on the type of equipment in your plant and on the recommendations of the manufacturers of your equipment.

4.810 Startup Procedures

1. Check the condition of all mechanical equipment for proper lubrication and operational status.
2. Make sure all chemical feeders are ready. There should be plenty of chemicals available in the tanks and hoppers and ready to be fed to the raw water.
3. Collect a sample of raw water and immediately run a jar test using fresh chemicals from the supply of chemicals to the feeders.
4. Determine the settings for the chemical feeders and set the feed rates on the equipment.
5. Open the inlet gate or valve to start the raw water flowing.
6. *IMMEDIATELY* start the selected chemical feed systems.
   a. Open valves to start feeding coagulant chemicals and dilution make-up water.
   b. Start chemical feeders.
   c. Adjust chemical feeders as necessary.
7. Turn on the flash mixer at the appropriate time. You may have to wait until the tank or channel is full before turning on the flash mixer. Follow the manufacturer's instructions.

NOTE: *DO NOT ALLOW ANY UNTREATED WATER TO GO THROUGH YOUR PLANT.* All raw water must be treated with alum or other appropriate coagulant. Water that has not been treated with a coagulant can go through your filter without proper treatment (removal of color and particulates) and into your distribution system.

8. Start the sample pumps as soon as there is water at each sampling location. Allow sufficient flushing time before collecting any samples.
9. Start the flocculators as soon as the first basin is full of water. Be sure to follow manufacturer's recommendations. If possible and appropriate, make any necessary adjustments in the speed.
10. Inspect mixing chamber and flocculation basins. Observe formation of floc and make any necessary changes.
11. Remove any debris floating on the water surface.
12. Perform water quality analyses and make process adjustments as necessary.
13. Calibrate chemical feeders.

4.811 Shutdown Procedures

1. Close raw water inlet gate or valve to flash-mix chamber or channel.
2. Shutdown the chemical feed systems.
   a. Turn off chemical feeders.
   b. Shut off appropriate valves.
   c. Flush or clean chemical feed lines if necessary.

3. Shutdown flash mixer and flocculators as water leaves each process. Follow manufacturer's recommendations.
4. Shutdown sample pumps before water leaves each sampling location.
5. Waste any water that has not been properly treated.
6. Lock out and tag appropriate electrical switches.
7. Dewater basins if necessary. Waste any water that has not been properly treated.

   DO NOT DEWATER BELOW GROUND BASINS WITHOUT CHECKING GROUNDWATER LEVEL.

   a. Close basin isolation gates or install stop-logs.
   b. Open basin drain valve(s).
   c. Be careful, basin may float or collapse depending on groundwater, soil or other conditions.

4.82 Recordkeeping

Good records of actions taken during startup/shutdown operations will assist the operator as well as other plant operations and maintenance personnel in conducting future shutdowns. The results of all inspections, equipment adjustments, and any special or unusual events should be accurately recorded.

4.83 Safety Considerations

Safety procedures are extremely important during startup and shutdown operations. In the coagulation-flocculation process you will be exposed to a variety of potentially hazardous situations which require the use of extreme caution. The operator may be exposed to electrical hazards, rotating and mechanical equipment, open-surface, water-filled basins (drowning), and empty basins. Also, the bottoms of empty basins are very slippery and a fall could be extremely painful and cause a serious injury. Always use safety devices such as handrails. For example, don't remove handrails to make your job easier.

In some instances, you may be required to make repairs in underground structures such as valve or pump vaults where you may be exposed to toxic and explosive gases or insufficient oxygen. Always make sure that these areas are properly ventilated. Use proper safety equipment such as hard hats, goggles, rubber boots, gas detectors and life jackets when necessary. Never enter a confined area or space alone. Be sure the person watching you has additional help standing by and knows how to evacuate you if you pass out.

DON'T TAKE ANY CHANCES

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 135.

4.8A Under what conditions are water treatment plants normally shut down?

4.8B Why is good recordkeeping important during startup/shutdown operations?

4.8C What safety hazards could be encountered during the startup or shutdown of a coagulation-flocculation process?

4.9 LABORATORY TESTS

4.90 Process Control Water Quality Indicators

In the operation of the coagulation-flocculation process, the operator will perform a variety of laboratory tests to monitor source water quality and to evaluate process performance. Process control water quality indicators of importance in the operation of the coagulation-flocculation process include turbidity, alkalinity, chlorine demand, color, pH, temperature and visual observations.

4.91 Sampling Procedures

Process water samples will be either grab samples obtained directly from a specific process monitoring location, or continuous samples which are pumped to the laboratory from various locations in the process (raw water, flash mixer effluent, flocculation basin effluent), as shown in Figure 4.8 on page 111. In either case, it is important to emphasize that process samples must be a *REPRESENTATIVE SAMPLE*[25] of actual conditions in the treatment plant. The accuracy and usefulness of laboratory analyses depends on the representative nature of the water samples.

The frequency of sampling for individual process control water quality indicators will vary, depending on the quality of the source water. Certain water quality indicators such as turbidity will be routinely monitored, while others such as alkalinity are sampled on a less frequent basis.

Process grab samples should be collected in clean plastic or glass containers and care should be used to avoid contamination of the sample, especially turbidity and odor samples.

Sample analysis should be done as soon as possible after the sample is collected. Important water quality indicators such as turbidity, temperature, chlorine demand, color, odor, pH and alkalinity can all change while waiting to be analyzed.

4.92 Sample Analysis

Analysis of certain process control water quality indicators such as turbidity and pH can be readily performed in the laboratory with the aid of automated analytical instruments such as turbidimeters and pH meters. Analysis of other process control water quality indicators, such as alkalinity and chlorine demand, may require *WET CHEMISTRY*[26] procedures which are often performed by a chemist or laboratory technician. A more detailed discussion of sampling and laboratory analytical procedures is also contained in Chapter 21, "Advanced Laboratory Procedures."

One of the most important laboratory procedures performed in the operation of the coagulation-flocculation process is the *JAR TEST PROCEDURE*. As discussed in an earlier section, this procedure is performed to establish the proper type and amount of chemical(s) to be used in the coagulation or flash-mixing process.

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[25] *Representative Sample. A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.*

[26] *Wet Chemistry. Laboratory procedures used to analyze a sample of water using liquid chemical solutions (wet) instead of, or in addition, laboratory instruments.*

4.93 Safety Considerations

Laboratory work may expose the operator to a number of different safety hazards. Care should be exercised in the handling of reagents and glassware. Use protective clothing (safety glasses and aprons) while performing wet chemical analyses, especially when handling dangerous chemicals such as acid or caustic solutions. Always perform in a well-ventilated space, and be familiar with the location and use of safety showers and eyewash facilities.

4.94 Recordkeeping

Record all laboratory test results on appropriate data sheets, and document in detail any unusual results.

Upon verification of abnormal test results, be sure to notify the proper personnel of your findings.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 135.

4.9A List the process control water quality indicators of importance in the operation of the coagulation-flocculation process.

4.9B When should sample analysis be performed to control the coagulation-flocculation process?

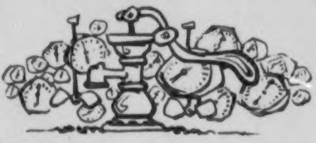
4.9C What safety hazards may be encountered when working in a laboratory?

4.10 PROCESS AND SUPPORT EQUIPMENT OPERATION AND MAINTENANCE

4.100 Types of Equipment

In the operation of the coagulation-flocculation process, the operator will be exposed to a variety of mechanical, electrical, and instrumentation equipment including:

1. Mixers and flocculators,
2. Chemical feeders,
3. Water quality monitors,
4. Pumps,
5. Valves,
6. Flow meters and gages, and
7. Control systems.



In the coagulation-flocculation process itself, chemical feeders (Figure 4.12) are of particular importance. Chemicals are normally fed at a fixed rate. This can be accomplished by liquid (solution) feed or by dry feed (volumetric or gravimetric). In liquid feed, a diluted solution of known concentration is prepared and fed directly into the water being treated. Liquid chemicals are fed through metering pumps and rotameters. Dry feeders deliver a measured quantity of dry chemical during a specified time interval. *VOLUMETRIC FEEDERS* deliver a specific volume of chemical during a given time interval, while *GRAVIMETRIC FEEDERS* deliver a predetermined weight of chemical in a specific unit of time. Generally, volumetric feeders can deliver smaller daily quantities of chemicals than gravimetric feeders, but the performance variables are:

1. Volumetric feeders are simpler and of less expensive construction, and
2. Gravimetric feeders are usually more easily adapted for recording the actual quantities of chemicals fed and for automatic control. For this reason, gravimetric feeders are generally used in large treatment plants.

Water treatment plants should have duplicate chemical feeders. This will permit the operator to maintain full service while a chemical feeder is "off-line" for routine maintenance or major repair. If this feature is not included in your plant, then consider requesting backup equipment as part of the annual operation, maintenance and repair budget request process.

The ultimate decision of which chemical feeder to use for a given application depends on the type of chemical compound, availability of chemical, chemical form (dry or liquid), and the amount to be fed daily.

4.101 Equipment Operation

Before starting a piece of mechanical equipment such as a mixer or chemical feeder, be sure that the unit is properly lubricated and its operational status is known. Also be certain that no one is working on the equipment. Be sure all valves are in the proper position before starting chemical feeders.

After startup, always check for excessive noise and vibration, overheating, and leakage (water, lubricants, and chemicals). When in doubt about the performance of a piece of equipment, always refer to operation and maintenance instructions or the manufacturer's technical manual.

Many equipment items such as valves and mixers are simple on/off devices with some provision for either speed or position adjustment. Other equipment items such as pumps and chemical feeders may require the use of special procedures for priming and calibration. Detailed operating and repair procedures are usually given in the plant operations and maintenance instructions for specific pieces of equipment.

During the course of normal operation, equipment should be periodically inspected for noise and vibration, leakage, overheating, or other signs of abnormal operation. Electrical motors should always be kept free of dirt, moisture, and obstructions to their ventilation openings.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 135.

4.10A What types of equipment are used in connection with the coagulation-flocculation process?

4.10B How do chemical liquid feeders work in the coagulation process?

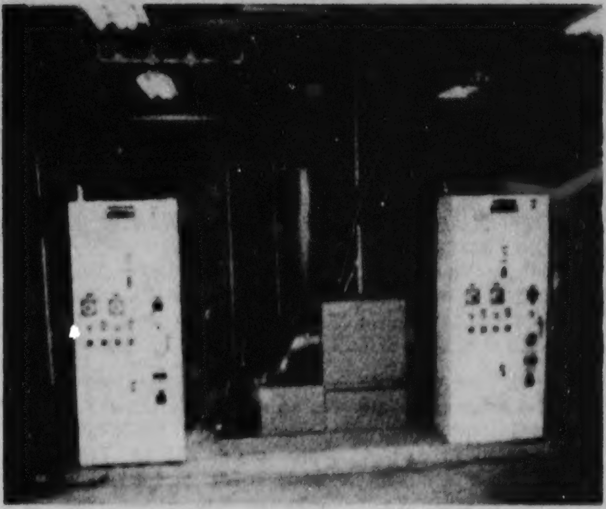
4.10C Selection of a chemical feeder for a given application depends on what factors?

4.102 Safety Considerations

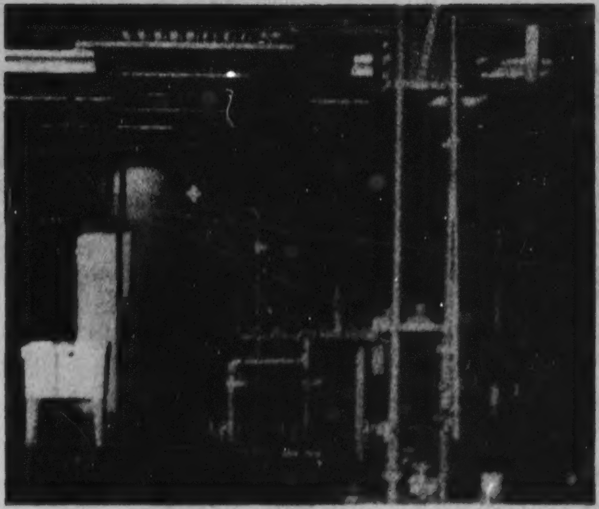
When working around electrical equipment such as motors, mixers, or flocculators, follow the safety procedures listed below to avoid accidents or injury.

ELECTRICAL EQUIPMENT

1. Always shut off power, lock out and attach safety tag before working on electrical equipment, instruments, controls, wiring and all mechanical equipment driven by electric motors,



Dry chemical make-up and feed system (polymer)



Solution chemical feed system (alum)
(Note graduated cylinder for calibration in right foreground)

Fig. 4.12 Chemical feeders

2. Avoid electrical shock by using protective gloves,
3. Use a volt meter to test for "live" wires and equipment,
4. Check grounds and avoid grounding yourself in water or in pipes,
5. Ground all electrical tools, and
6. Use the buddy system.

MECHANICAL EQUIPMENT

1. Use protective guards on rotating equipment,
2. Do not wear loose clothing, worn gloves or long hair around rotating equipment, and
3. Clean up all lubricant spills (oil and grease).

OPEN WATER SURFACE STRUCTURES

1. Do not avoid or defeat protective devices such as handrails by removing them when they are in the way,
2. Close all openings when finished, and
3. Know the location of all life preservers and wear one when necessary.

VALVE AND PUMP VAULTS

1. Be sure all underground structures are free of hazardous atmospheres (toxic and explosive gases or insufficient oxygen) by using gas detectors,
2. Only work in well-ventilated structures, and
3. Use the buddy system.

HANDLING ALUM

Normal precautions should be used to prevent spraying or splashing of liquid alum, especially when the liquid is hot. Face shields can be worn to protect your eyes. A rubber apron and waterproof sleeves may be used to protect your clothing.

Both liquid alum and dry alum dust must be flushed from your eyes immediately. Use great amounts of warm water. Alum must be washed from your skin because prolonged contact can be irritating.

For more details on safety, see Chapter 20, "Safety."

4.103 Preventive Maintenance Procedures

Preventive maintenance programs are designed to assure the satisfactory long-term operation of treatment plant facilities under a variety of different operating conditions. Scheduled or routine maintenance of valves, mixers, pumps, and chemical feeders is an important part of the preventive maintenance program. The operator will be expected to perform routine maintenance functions as part of an overall preventive maintenance program. Typical functions include:

1. Keeping motors free of dirt and moisture,
2. Assuring good ventilation (air circulation) in equipment work areas,
3. Checking pumps for leaks, unusual noise, vibrations, or overheating,
4. Maintaining proper lubrication and oil levels,
5. Inspecting for alignment of shafts and couplings,

6. Checking bearings for wear, overheating and proper lubrication,
7. Exercise infrequently used valves on a regular schedule and check all valves for proper operation, and
8. Calibration of flow meters and chemical feeders.

Good recordkeeping is the key to a successful preventive maintenance program. These records provide maintenance and operations personnel with clues for determining the causes of equipment breakdowns, and will often times show weaknesses in a particular piece of equipment which can be corrected prior to failure.

For more details on maintenance, see Chapter 18, "Maintenance."

4.11 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read all of Section A.4, "Metric System."

In Section A.13, "Typical Water Treatment Plant Problems," read and work the problems in the following sections:

1. A.130 Flows,
2. A.131 Chemical Doses,
3. A.132 Reservoir Management and Intake Structures, and
4. A.133 Coagulation and Flocculation.

4.12 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 4, "Water Chemistry," and Chapter 7, "Chemical Coagulation."
2. *TEXAS MANUAL*, Chapter 6, "Water Chemistry," and Chapter 8, "Coagulation and Sedimentation."

4.13 ACKNOWLEDGMENT

Many of the concepts and procedures discussed in this chapter are based on material obtained from the sources listed below.

1. Stone, B. G. Notes from "Design of Water Treatment Systems," CE-610, Loyola Marymount University, Los Angeles, Ca., 1977.
2. *WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES*, American Water Works Association, Third Edition, McGraw-Hill, 1971. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10008, price to members $29.00; nonmembers, $35.50.
3. *WATER TREATMENT PLANT DESIGN*, prepared jointly by the American Water Works Association, and Conference of State Sanitary Engineers, AWWA, 1969. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10006, price to members, $7.50; nonmembers, $15.00.
4. *OPERATION AND MAINTENANCE MANUAL FOR STOCKTON EAST WATER TREATMENT PLANT*, James M. Montgomery, Consulting Engineers, Inc., Walnut Creek, Ca., 1979.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 135.

4.10D Underground structures could present what types of hazards?

4.10E What equipment should be part of a preventive maintenance program for a coagulation-flocculation process?

End of Lesson 3 of 3 Lessons
on
Coagulation and Flocculation

DISCUSSION AND REVIEW QUESTIONS

Chapter 4. COAGULATION AND FLOCCULATION

(Lesson 3 of 3 Lessons)

Write the answers to these questions in a notebook before continuing with the objective test on page 135. The question numbering continues from Lesson 2.

16. What would you do if you discovered abrupt changes in the source water or filtered water turbidity?
17. What would you do if the chlorine demand of the source water increased?
18. What changes in the coagulation-flocculation process would you consider if a change in source water quality caused water quality problems in the filtered water?
19. Which coagulation-flocculation process changes may require notification of others?
20. Why must representative samples be collected?

SUGGESTED ANSWERS

Chapter 4. COAGULATION AND FLOCCULATION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 100.

4.0A The purpose of coagulation and flocculation is to remove particulate impurities and color from the water being treated.

4.1A In the *COAGULATION PROCESS*, chemicals are added which will cause the particles to begin to clump together. The particles gather together to form larger, settleable particles in the *FLOCCULATION PROCESS*.

Answers to questions on page 105.

4.2A The primary purpose of the flash mixing is to rapidly mix and uniformly (evenly) distribute the coagulant chemical throughout the water.

4.2B *PRIMARY COAGULANTS* are used to cause the particles to clump together. *COAGULANT AIDS* are used to add density to slow-settling flocs, and to add toughness so the floc will not break up in subsequent processes.

4.2C Four methods of mixing coagulant chemicals include:

1. Hydraulic mixing,
2. Mechanical mixing,
3. Diffusers and grid systems, and
4. Pumped blenders.

4.2D Baffles or throttling valves are hydraulic mixers.

Answers to questions on page 106.

4.3A Flocculation is a slow stirring process that causes the gathering together of small, coagulated particles into larger settleable floc particles.

4.3B The typical mixing time in the coagulation process is several seconds.

4.3C The minimum detention time recommended for flocculation ranges from about 5 to 20 minutes for direct filtration systems and up to 30 minutes for conventional filtration.

4.3D An advantage of vertical flocculators over horizontal ones is that vertical flocculators usually require less maintenance since they eliminate submerged bearings and packings.

4.3E The compartments in flocculation basins are separated by baffles to prevent short-circuiting of the water being treated, and to reduce the level of turbulence in each succeeding compartment by reducing the speed of the stirrers. This is called tapered-energy mixing.

Answers to questions on page 108.

4.4A Coagulation-flocculation influences the effectiveness of the sedimentation, filtration and disinfection processes. The removal of particulates by the sedimentation and filtration processes depends on effective coagulation-flocculation. Coagulation-flocculation causes bacteria and other disease-causing organisms to be bound up in suspended solids and floc. If not removed by sedimentation and/or filtration, bacteria may be shielded from disinfection and released into the distribution system.

4.5A The most important consideration in coagulation-flocculation process control is the selection of the proper type and amount of coagulant chemical(s) to be applied to the water being treated.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 111.

4.6A Sedimentation and filtration are used to remove suspended solids after the coagulation-flocculation process.

4.6B The effectiveness of the solids removal processes is commonly monitored by measuring the turbidity of filtered water.

4.6C Typical functions performed by an operator in the normal operation of the coagulation-flocculation process include the following:

1. Monitor process performance,
2. Evaluate water quality conditions,
3. Check and adjust process controls and equipment, and
4. Visually inspect facilities.

4.6D The most common laboratory tests used to monitor the coagulation-flocculation process are turbidity, alkalinity, temperature, color, pH and chlorine demand.

4.6E Visual observations of the coagulation-flocculation process generally include observing the degree of agitation of the water in the flash-mixing channel or chamber, and observing the size and distribution of floc in the flocculation basin. An uneven distribution of floc could be an indication of short-circuiting in the flocculation basin, while floc particles which are too small or too large may be difficult to remove in subsequent processes.

Answers to questions on page 114.

4.6F Water flowing through the typical treatment plant after the flash mixer flows through the flocculation, sedimentation and filtration processes.

4.6G Detention times in flash-mix chambers and flocculation basins decrease when the flow increases.

$$\text{Detention Time, min} = \frac{\text{Chamber or Basin Volume gal}}{\text{Flow, gal/min}}$$

4.6H

Known	Unknown
Flash Mix Chamber	Detention Time, sec

Length, ft = 6 ft
Width, ft = 4 ft
Depth, ft = 5 ft
Flow, MGD = 10 MGD

1. Calculate the volume of the flash-mix chamber in cubic feet and then in gallons.

$$\begin{aligned}\text{Volume, cu ft} &= (\text{Length, ft})(\text{Width, ft})(\text{Depth, ft})\\ &= (6\text{ ft})(4\text{ ft})(5\text{ ft})\\ &= 120\text{ cu ft}\end{aligned}$$

$$\begin{aligned}\text{Volume, gal} &= (120\text{ cu ft})(7.48\text{ gal/cu ft})\\ &= 898\text{ gal}\end{aligned}$$

2. Calculate the detention time in seconds.

$$\begin{aligned}\text{Detention Time, sec} &= \frac{(\text{Volume, gal})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}{\text{Flow, gal/day}}\\ &= \frac{(898\text{ gal})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}{10{,}000{,}000\text{ gal/day}}\\ &= 7.7\text{ sec}\end{aligned}$$

4.6I Jar test reagents can be prepared by using the actual chemical coagulants used to treat the water, or they may be obtained from a chemical supplier in some cases.

Answers to questions on page 121.

4.6J Only *ONE* variable at a time should be changed when running a jar test so that all observed changes can be attributed to the one variable.

4.6K A jar test sample should not be collected in advance because the temperature of the water being tested should be approximatley the same as the temperature of the water being treated.

4.6L When evaluating the results of jar tests, the following factors should be considered:

1. Rate of floc formation,
2. Type of floc particles,
3. Clarity of water between floc particles,
4. Size of floc,
5. Amount of floc formed,
6. Floc settling rate, and
7. Clarity of water above settled floc.

Answers to questions on page 124.

4.6M Operators should keep accurate records in order to obtain a running account of operations (historical records); to have a source of information for assistance in solving current or future process problems; and to comply with regulatory requirements.

4.6N All record entries should include the date, time of an event, and initials of operator making entry.

4.6O The safety hazards an operator may encounter when operating a coagulation-flocculation process include:

1. Electrical equipment,
2. Rotating mechanical equipment,
3. Water treatment chemicals,
4. Laboratory reagents (chemicals),
5. Slippery surfaces caused by wet polymers,
6. Open-surface, water-filled structures (drowning), and
7. Confined spaces and underground structures such as valve or pump vaults (toxic and explosive gases, insufficient oxygen).

4.6P Good communications are essential to advise other operators and support personnel of current process conditions and unusual events.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 126.

4.7A Sudden changes in either raw or filtered water turbidity, pH, alkalinity, temperature, or chlorine demand, are signals that the operator should immediately review the performance of the coagulation-flocculation process.

4.7B Significant changes in source water turbidity levels, either increases or decreases, generally require that the operator verify the effectiveness of the coagulant chemicals and dosages being applied at the flash mixer.

4.7C The best way to verify the effectiveness of the coagulant chemicals and dosages is by performing a series of jar tests in the laboratory to simulate process performance in the treatment plant.

4.7D Sudden water temperature changes may require coagulant dosage changes and an adjustment in the level of mixing intensity in the flash mixers or flocculators.

Answers to questions on page 128.

4.7E Good recordkeeping is especially important during abnormal plant operating conditions to document the unique or special event and the actions taken by the operator to solve the problem. These records also may be helpful from a legal or regulatory agency perspective.

4.7F During abnormal operating conditions, more frequent turbidity, alkalinity, pH and jar tests may be required.

4.7G An emergency response procedure should be developed for every water treatment plant so that notification of the proper personnel can be accomplished and the emergency resolved.

Answers to questions on page 129.

4.8A Water treatment plants are normally shut down for periodic maintenance and only rarely due to a major process failure.

4.8B Good documentation of actions taken during startup/shutdown operations will assist the operator as well as other plant operations and maintenance personnel in conducting future shutdowns.

4.8C Safety hazards that could be encountered during the startup or shutdown of a coagulation-flocculation process include electrical shocks, rotating mechanical equipment, and open-surface, water-filled basins (drowning). Also the bottoms of empty basins are very slippery and a fall could be extremely painful and cause serious injury. Underground structures such as valve or pump vaults could contain toxic or explosive gases or insufficient oxygen.

Answers to questions on page 130.

4.9A The process control water quality indicators of importance in the operation of the coagulation-flocculation process include turbidity, temperature, alkalinity, chlorine demand, color, pH, and odor.

4.9B Sample analysis should be performed immediately following sample collection.

4.9C Safety hazards encountered in the laboratory include the handling of reagents and glassware.

Answers to questions on page 130.

4.10A Types of equipment used in connection with the coagulation-flocculation process include mixers and flocculators, chemical feeders, water quality monitors, pumps, valves, flow meters, gages and control systems.

4.10B Chemical liquid feeders feed a solution of known concentration directly into the water being treated.

4.10C Selection of a chemical feeder for a given application depends on the type of chemical compound, chemical form (dry or liquid), and the amount to be fed daily.

Answers to questions on page 132.

4.10D Underground structures could present hazardous atmospheres containing toxic or explosive gases or insufficient oxygen.

4.10E Equipment that should be part of a preventive maintenance program include valves, mixers, pumps, and chemical feeders.

OBJECTIVE TEST

Chapter 4. COAGULATION AND FLOCCULATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Surface water sources may become polluted by both man and nature.
   1. True
   2. False

2. Larger sized particles such as sand and heavy silts are commonly removed from water by coagulation and flocculation.
   1. True
   2. False

3. In the coagulation process, soluble flocs are formed by the addition of coagulant chemicals.
   1. True
   2. False

4. Floc gathers together during the flash-mixing process.
    1. True
    2. False

5. Some flocculation can be accomplished by the turbulence resulting in conduits or channels.
    1. True
    2. False

6. Optimum flocculation is usually achieved in one large basin.
    1. True
    2. False

7. Disinfection of water can become more effective as a result of poor coagulation-flocculation performance.
    1. True
    2. False

8. The water quality of a water source from a river is usually more stable or constant than water from a large lake or reservoir.
    1. True
    2. False

9. An even distribution of floc in the flocculation basin could be an indication of short-circuiting.
    1. True
    2. False

10. Operators should routinely perform visual inspections of the overall coagulation-flocculation facilities.
    1. True
    2. False

11. Accurate records provide the factual account of your operation which is required to meet legal and regulatory agency needs.
    1. True
    2. False

12. Operators should be familiar with general first aid practices such as mouth-to-mouth resuscitation.
    1. True
    2. False

13. Decreasing source water turbidity is more difficult to treat than increasing turbidity (which has larger particle sizes).
    1. True
    2. False

14. Good communications are an essential part of the operator's job.
    1. True
    2. False

15. During periods of abnormal operating conditions, demands on the operator's time will be significantly increased.
    1. True
    2. False

MULTIPLE CHOICE

16. The coagulation process usually occurs during
    1. 5 seconds.
    2. 1 minute.
    3. 5 minutes.
    4. 10 minutes.
    5. 1 hour.

17. Metallic salts are commonly used as chemical coagulants due to their
    1. Ability to increase alkalinity.
    2. Ease of application.
    3. Effectiveness.
    4. Relatively low cost.
    5. Safety aspects.

18. Which coagulant mixer consumes the greatest amount of electrical energy?
    1. Baffles
    2. Grid System
    3. Pump blenders
    4. Throttling valves
    5. Turbines

19. An efficient flocculation process involves
    1. Adequate floc collectors.
    2. Appropriate stirring time.
    3. Means of creating stirring action.
    4. Proper mixing action.
    5. Properly shaped mixing basin.

20. Flocculation can be accomplished by the turbulence resulting from
    1. Head losses associated with baffles.
    2. Paddle wheels.
    3. Propellers.
    4. Turbidimeters.
    5. Turbines.

21. Laboratory tests used to monitor the coagulation-flocculation process include
    1. Alkalinity.
    2. Chloride.
    3. pH.
    4. Temperature.
    5. Turbidity.

22. In the normal operation of the coagulation-flocculation process, an operator would be expected to
    1. Check and adjust process equipment.
    2. Check bearings for wear.
    3. Evaluate water quality conditions.
    4. Monitor process performance.
    5. Visually inspect facilities.

23. In the coagulation-flocculation process, records should be maintained of
    1. Process equipment performance.
    2. Process flow sequence.
    3. Process production inventory.
    4. Process water quality.
    5. Source water quality.

24. Process production inventory records include
    1. Amount of chemicals in storage.
    2. Amount of water processed.
    3. Chemical feed rates.
    4. Chemicals used.
    5. Operator safety records.

25. Sudden changes in which of the following water quality indicators in the raw or filtered water are signals that the operator should immediately review the performance of the coagulation-flocculation process?
    1. Alkalinity
    2. Chlorine demand
    3. Coliforms
    4. Temperature
    5. Turbidity

26. Changes in the chlorine demand in the influent to the coagulation-flocculation process may indicate
    1. Changes in chlorine demand in source water.
    2. Changes in hardness in source water.
    3. Changes in laboratory reagents.
    4. Failure in plant prechlorination feed system.
    5. Failure of flash mixer.

27. If you observed problems with floc formation in the flocculation basin, what process changes would you consider?
    1. Adjust chlorine dosage
    2. Adjust coagulant dosage
    3. Adjust flash mixer
    4. Adjust flocculator mixing intensity
    5. Change coagulant

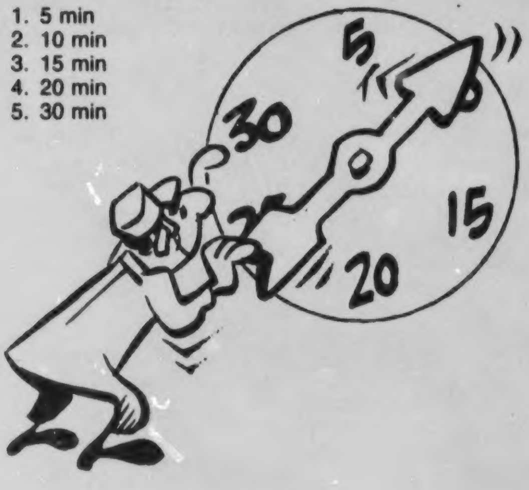
28. Which of the following coagulation-flocculation process changes may require notification of others?
    1. Equipment failure
    2. Lack of response to change in coagulant dosage
    3. Operator changing doses in jar tests
    4. Power outages
    5. Radical changes in source water quality

29. Selection of a chemical feeder for a given application is based upon
    1. Amount of chemical to be fed.
    2. Chemical form (dry or liquid).
    3. Storage characteristics of chemicals.
    4. Type of chemical compound.
    5. Water quality of source water.

30. The main purpose of the jar test is to determine the best
    1. Chlorine residual.
    2. Coagulant dosage.
    3. Detention time.
    4. Filtration rate.
    5. Particulate settling velocity.

31. Jar tests should be performed whenever changes occur in the raw water
    1. Alkalinity.
    2. Dissolved oxygen.
    3. Hardness.
    4. pH.
    5. Turbidity.

32. Estimate the detention time (minutes) in a rectangular flocculation basin when the flow is 1.6 MGD. The basin is 30-feet long, 20-feet wide and 8-feet deep. Select the closest answer.
    1. 5 min
    2. 10 min
    3. 15 min
    4. 20 min
    5. 30 min



33. Determine the setting on a dry alum feeder in pounds per day when the flow is 1.3 MGD. Jar tests indicate that the best alum dose is 12 mg/*L*.
    1. 2 lbs/day
    2. 15 lbs/day
    3. 30 lbs/day
    4. 75 lbs/day
    5. 130 lbs/day

34. The average daily flow for a water treatment plant is 0.75 MGD. Jar test results indicate that the best polymer dosage is 1.8 mg/*L*. How many pounds of polymer will be used in 30 days?
    1. 5 lbs
    2. 11 lbs
    3. 130 lbs
    4. 150 lbs
    5. 340 lbs

35. A water treatment plant used 27 pounds of cationic polymer to treat 1.6 million gallons of water during a 24-hour period. What is the polymer dosage in mg/*L*?
    1. 2 mg/*L*
    2. 5 mg/*L*
    3. 18 mg/*L*
    4. 36 mg/*L*
    5. 360 mg/*L*

36. Liquid polymer is supplied to a water treatment plant as an eight-percent solution. How many gallons of liquid polymer should be mixed in a tank to produce 200 gallons of 0.7 percent polymer solution?
    1. 2.5 gallons
    2. 7.5 gallons
    3. 12.5 gallons
    4. 17.5 gallons
    5. 22.5 gallons

37. Liquid alum delivered to a water treatment plant contains 542.3 milligrams of alum per milliliter of liquid solution. Jar tests indicate that the best alum dose is eight mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the flow is 2.2 MGD. There are 3.785 liters in one gallon.

1. 19 m*L*/min
2. 72 m*L*/min
3. 90 m*L*/min
4. 123 m*L*/min
5. 207 m*L*/min

END OF OBJECTIVE TEST

APPENDIX

A. Preparation of Detention Time Curves
B. Adjustment and Calibration of Chemical Feeders

A. *PREPARATION OF DETENTION TIME CURVES*

Example 2 (page 112) was a water treatment plant with a flow of 2.4 MGD. The flocculation basin was 8-feet deep, 15-feet wide, and 45-feet long. We calculated a basin volume of 40,392 gallons and a detention time of 24 minutes. The typical flows for this plant range from 0.8 MGD to 2.4 MGD. To plot a detention time curve, we should have at least four plotting points. This means that we must calculate the detention times for at least four flows. For this example we will calculate the detention times for flows of 0.8, 1.2, 1.6, 2.0 and 2.4 MGD. This will provide us with five plotting points.

Known		**Unknown**
Basin Volume, gal	= 40,392 gal	Detention Time, min, for each flow
Flows, MGD	= 0.8, 1.2, 1.6, 2.0 and 2.4 MGD	

1. Calculate the detention time in minutes for each flow.

$$\text{Detention Time, min} = \frac{(\text{Volume, gal})\ (24\ \text{hr/day})\ (60\ \text{min/hr})}{\text{Flow, gal/day}}$$

$$\text{Detention Time, min for 0.8 MGD} = \frac{(40{,}392\ \text{gal})\ (24\ \text{hr/day})\ (60\ \text{min/hr})}{800{,}000\ \text{gal/day}}$$

$$\text{or} = \frac{58{,}164{,}480^{a}}{800{,}000\ \text{gal/day}}$$

$$= 73\ \text{min}$$

$$\text{Detention Time, min for 1.2 MGD} = \frac{58{,}164{,}480}{1{,}200{,}000\ \text{gal/day}}$$

$$= 48\ \text{min}$$

$$\text{Detention Time, min for 1.6 MGD} = \frac{58{,}164{,}480}{1{,}600{,}000\ \text{gal/day}}$$

$$= 36\ \text{min}$$

$$\text{Detention Time, min for 2.0 MGD} = \frac{58{,}16{,}480}{2{,}000{,}000\ \text{gal/day}}$$

$$= 29\ \text{min}$$

$$\text{Detention Time, min for 2.4 MGD} = \frac{58{,}164{,}480}{2{,}400{,}000\ \text{gal/day}}$$

$$= 24\ \text{min}$$

2. Summarize the calculated plotting points.

Flow, MGD	**Detention Time, Min**
0.8	73
1.2	48
1.6	36
2.0	29
2.4	24

3. Plot the flow vs. detention time curve as shown in Figure 4.13. This curve can be used to determine the detention time for any flow. If you know the flow you are treating, find the flow on Figure 4.13, move across to the curve, and then down to the detention time scale.

B. *ADJUSTMENT AND CALIBRATION OF CHEMICAL FEEDERS*

The capacity rating of solution chemical feeders is usually given in units of gallons per minute (GPM) or gallons per hour (GPH), while dry feeders are often rated by the maximum amount of chemical that can be fed in a 24-hour period (pounds per day).

Adjusting or changing the amount of chemical to be fed is generally accomplished by manually changing the feed rate setting on the chemical feeder. Adjustment is physically performed by turning a knob, adjusting a wheel, or by rotating a hand-crank.

Typically, a feed-rate scale is provided on the chemical feeder which is calibrated over a range from zero to 100 percent of maximum feed rate, for both solution and dry chemical feeders. In a solution feed system, if the desired feed rate is 3 GPH and the chemical feeder has a maximum feed rate of 15 GPH, then the feeder would be set at:

$$\text{Scale Setting, \%} = \frac{(\text{Desired Feed Rate, GPH})\ 100\%}{\text{Maximum Feed Rate, GPH}}$$

$$= \frac{(3\ \text{GPH})\ (100\%)}{15\ \text{GPH}}$$

$$= 20\ \%\ \text{of full setting}$$

---

[a] *58,164,480 will be a constant for all calculations. You can determine this constant for your plant.*

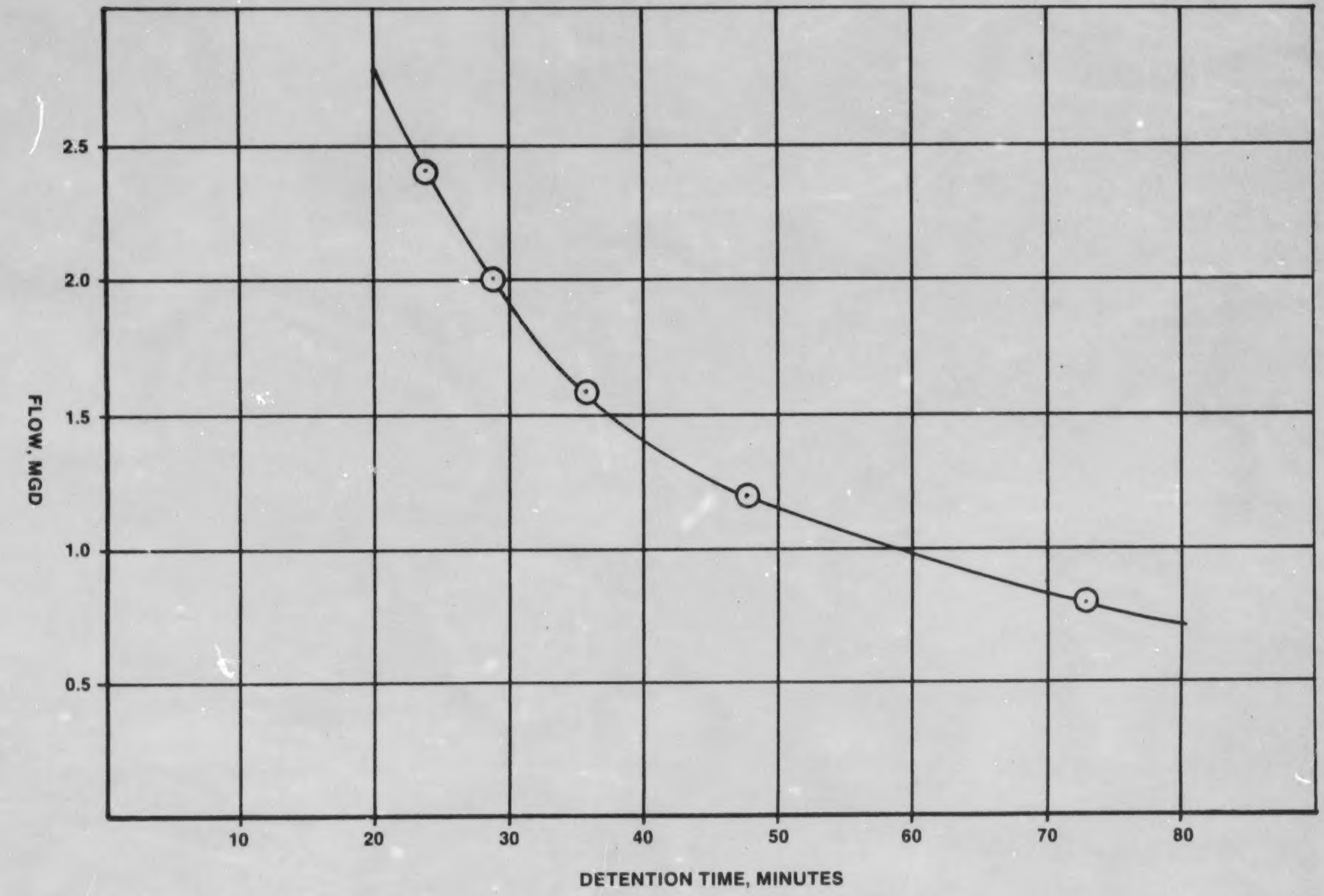


Fig. 4.13 Development of flow vs. detention time curve

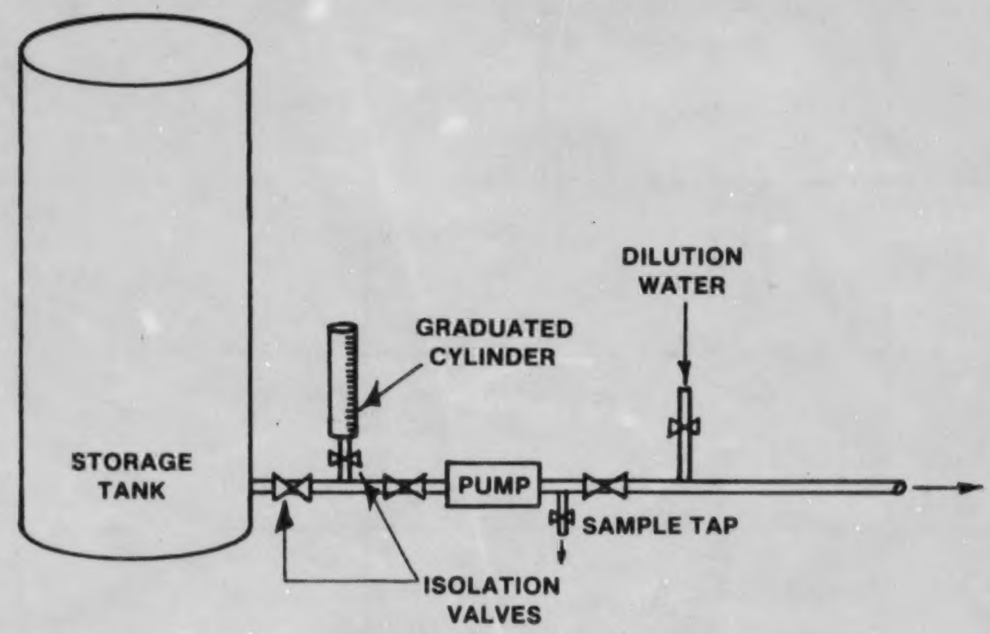


Fig. 4.14 Calibration system

Likewise, in a dry feed system, if the desired feed rate is 150 pounds per day and the chemical feeder has a maximum feed rate of 300 pounds per day, then the feeder would be set at:

$$\text{Feeder Setting, \%} = \frac{(\text{Desired Feed Rate, lbs/day})(100\%)}{\text{Maximum Feed Rate, lbs/day}}$$

$$= \frac{(150\text{ lbs/day})(100\%)}{300\text{ lbs/day}}$$

$$= 50\%\text{ of full scale}$$

Chemical feed systems should be calibrated at least once per shift to verify proper chemical feed rate. Always calibrate chemical feeders against working system pressures to avoid errors. In liquid chemical feed systems, the *VOLUMETRIC METHOD* is probably the most accurate calibration technique. This method involves the use of a calibrated container (usually a graduated cylinder as shown in Figure 4.12, page 131) and a stopwatch to determine the volume of chemical fed during a given time period. Ideally the cylinder and timer are part of the chemical feeder piping system (Fig. 4.12). This procedure can, of course, be used to calibrate the chemical feed pump over the full range of feed rates.

To apply the procedure, select an appropriate time period such as 30 to 90 seconds. The time period should be increased when measuring dilute chemical solutions to assure accurate results. Fill the graduated container with a convenient amount of the chemical solution. Insert one end of a tube into the container with the chemical and attach the other end to the feeder inlet on the suction side of the feeder. Start the feeder and the stopwatch. After a minimum time period (for example, 30 seconds), read the graduation mark on the container that corresponds to the liquid level drawdown. Record the total elapsed time. The following example uses a one-liter graduated cylinder.

EXAMPLE 13

A chemical feeder draws a liquid chemical from a one-liter (100 mL) graduated cylinder for 30 seconds. At the end of 30 seconds, the graduated cylinder has 400 mL remaining. What is the chemical feed rate in milliliters per minute and in gallons per minute (GPM)?

Known	Unknown
One liter of chemical	Chemical Feed Rate, mL/min and GPM
Starting level, mL = 1000 mL	
Final level, mL = 400 mL	
Feed time, sec = 30 sec	

1. Determine volume of chemical fed in milliliters.

$$\text{Chemical Fed, mL} = \text{Starting Level, mL} - \text{Final Level, mL}$$

$$= 1000\text{ mL} - 400\text{ mL}$$

$$= 600\text{ mL}$$

2. Determine chemical feed rate, mL/min.

$$\begin{array}{c}\text{Chemical Feed}\\ \text{Rate, mL/min}\end{array} = \frac{\text{Chemical Fed, mL}}{\text{Feed Time, min}}$$

$$= \frac{(600\text{ mL})(60\text{ sec/min})}{30\text{ sec}}$$

$$= 1200\text{ mL/min}$$

3. Calculate chemical feed rate in GPM.

$$\begin{array}{c}\text{Chemical Feed}\\ \text{Rate, GPM}\end{array} = \frac{(\text{Chemical Feed Rate, mL/min})}{3785\text{ mL/gal}}$$

$$= \frac{1200\text{ mL/min}}{3785\text{ mL/gal}}$$

$$= 0.32\text{ GPM}$$

Compare your calculated value with the setting on the chemical feeder and any calibration tables you may have. If the values do not agree, recheck your work and then adjust the feeder to deliver the correct amount of chemical. If the chemical feeder has a setting (say, 1, 2, 3), record the chemical feed rate as 0.32 GPM for the actual setting. Adjust the feeder to another setting (higher or lower) and repeat the test to determine the feed rate at the new setting.

Most chemical feed systems are not furnished with volumetric calibration accessories. However, this feature can be readily added to existing systems by purchasing a standard laboratory-grade graduated cylinder (preferably plastic), a stopwatch, and installing the necessary piping and valving on the pump suction. Figure 4.14 is a sketch of a typical installation. Another approach is to open a sample tap and pump directly into a graduated cylinder.

Procedures similar to those described above can be used for dry feed applications by measuring the dry weight of chemical fed during a given time period.

EXAMPLE 14

An empty bucket weighs 0.8 pounds. This bucket is placed under a dry chemical feeder. After 24 minutes the bucket weighs 5.6 pounds.[27] Estimate the chemical feed rate in pounds per day.

Known		Unknown
Weight of Empty Bucket, lbs	= 0.8 pounds	Dry Chemical Feed Rate, lbs/day
Weight of Bucket and Chemical, lbs	= 5.6 pounds	
Feed Time, min	= 24 minutes	

1. Determine the amount of chemical fed in pounds

$$\text{Chemical Fed, lbs} = \text{Weight of Bucket and Chemical, lbs} - \text{Weight of Empty Bucket, lbs}$$
$$= 5.6 \text{ lbs} - 0.8 \text{ lbs}$$
$$= 4.8 \text{ lbs}$$

2. Calculate the dry chemical feed rate in pounds per minute.

$$\text{Chemical Feed Rate, lbs/min} = \frac{\text{Chemical Fed, lbs}}{\text{Feed Time, min}}$$
$$= \frac{4.8 \text{ lbs}}{24 \text{ min}}$$
$$= 0.2 \text{ lbs/min}$$

3. Calculate the dry chemical feed rate in pounds per day.

$$\text{Chemical Feed Rate, lbs/day} = (\text{Chemical Feed Rate, lbs/min})(60 \text{ min/hr})(24 \text{ hr/day})$$
$$= (0.2 \text{ lbs/min})(60 \text{ min/hr})(24 \text{ hr/day})$$
$$= 288 \text{ lbs/day}$$

EXAMPLE 15

An empty pie tin weighs 30 grams. This tin is placed under a dry chemical feeder. After 5 minutes the pie tin weighs 450 grams. Estimate the chemical feed rate in grams per minute.

Known		Unknown
Weight of Empty Tin, gm	= 30 gm	Dry Chemical Feed Rate, gm/min
Weight of Tin and Chemical, gm	= 450 gm	
Feed Time, min	= 5 min	

1. Determine the amount of chemical feed in grams.

$$\text{Chemical Fed, gm} = \text{Weight of Tin and Chemical, gm} - \text{Weight of Empty Tin, gm}$$
$$= 450 \text{ gm} - 30 \text{ gm}$$
$$= 420 \text{ grams}$$

2. Calculate the dry chemical feed rate in grams per minute.

$$\text{Chemical Rate, gm/min} = \frac{\text{Chemical Fed, gm}}{\text{Feed Time, min}}$$
$$= \frac{420 \text{ grams}}{5 \text{ min}}$$
$$= 84 \text{ grams/min}$$

A check on the amount of liquid chemical used in a given time period, say 24 hours, can be made by measuring the difference (drawdown) in chemical storage tank levels (Figure 4.15). In this case, the operator must compute the volume of chemical used based upon the dimensions of the storage tank. Some small chemical storage tanks are mounted on a scale, thus allowing a direct reading of amount of chemical remaining at the end of each day. The difference between these values is the amount used per day.

EXAMPLE 16

An alum storage tank has an inside diameter (I.D.) of 10 feet and a height of 25 feet. Duringa 24-hour time period (say 8:00 am Monday to 8:00 am Tuesday), the tank level dropped three inches (3 in/12 in/ft = 0.25 ft). How many gallons of chemical were used? If the chemical feed was constant, what was the chemical feed rate in gallons per minute (GPM)?

Known		Unknown
Tank Diameter, ft	= 10 ft	Chemical Used, gal
Tank Height, ft	= 25 ft	Chemical Feed Rate, GPM
Tank Drop, ft	= 0.25 ft	
Time, hr	= 24 hours	

---

[27] *If you can't get a bucket this big in your chemical feeder to collect a sample or leave it in the feeder this long, use a pie tin. Some operators will collect three samples of three minutes or five minutes each and use a total amount of chemical fed for nine or fifteen minutes.*

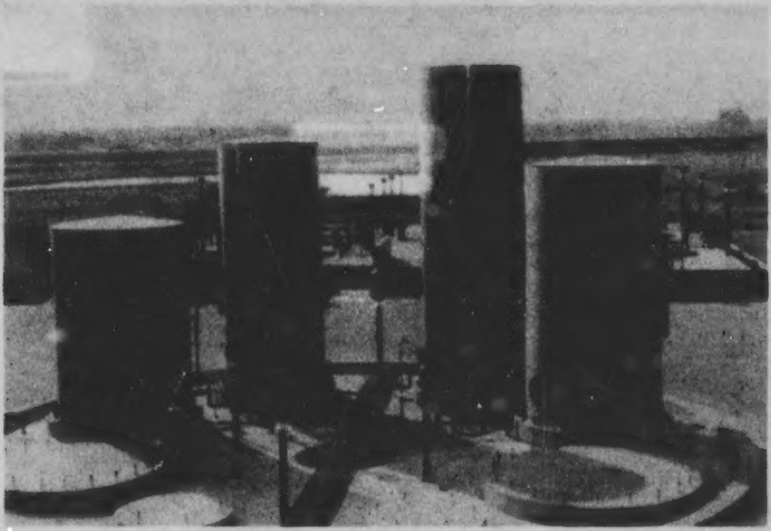


Fig. 4.15 Chemical storage tanks

1. Calculate the volume of chemical used in cubic feet.

$$\text{Volume, cu ft} = (\pi/4)(\text{Diameter, ft})^2(\text{Depth Drop, ft})$$

$$= (0.785)(10\text{ ft})^2(0.25\text{ ft})$$

$$= 19.63\text{ cu ft}$$

2. Determine the volume of chemical used in gallons.

$$\text{Chemical Used, gal} = (\text{Volume, cu ft})(7.48\text{ gal/cu ft})$$

$$= (19.63\text{ cu ft})(7.48\text{ gal/cu ft})$$

$$= 147\text{ gallons}$$

3. Calculate the chemical feed rate in gallons per minute.

$$\text{Chemical Feed Rate, GPM} = \frac{(\text{Chemical Used, gallons})}{(\text{Time, hours})(60\text{ min/hr})}$$

$$= \frac{147\text{ gallons}}{(24\text{ hours})(60\text{ min/hr})}$$

$$= 0.10\text{ GPM}$$

CHAPTER 5

SEDIMENTATION

by

Jim Beard

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OBJECTIVES

Chapter 5. SEDIMENTATION

Following completion of Chapter 5, you should be able to:

1. Identify factors affecting the performance of sedimentation basins,
2. Describe various types of sedimentation basins and how they work,
3. Start up and shut down sedimentation basins,
4. Operate and maintain a sedimentation process and basins,
5. Collect samples and analyze results for a sedimentation process,
6. Keep records of a sedimentation process and basins, and
7. Safely perform your duties around a sedimentation basin.

GLOSSARY

Chapter 5. SEDIMENTATION

ABSORPTION (ab-SORP-shun) **ABSORPTION**

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

CATHODIC PROTECTION (ca-THOD-ick) **CATHODIC PROTECTION**

A system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic and concentrates corrosion on auxiliary anodic parts used for the purpose of corrosion instead of the structure.

CLARIFIER (KLAIR-uh-fire) **CLARIFIER**

A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom. Clarifiers are also called SETTLING BASINS and SEDIMENTATION BASINS.

COMPLETE TREATMENT **COMPLETE TREATMENT**

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called CONVENTIONAL FILTRATION.

DENSITY (DEN-sit-tee) **DENSITY**

A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DETENTION TIME **DETENTION TIME**

(1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow.

(2) The actual time in hours, minutes or seconds a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber. In storage reservoirs, detention time is the length of time entering water will be held before being drafted for use (several weeks to years, several months being typical).

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})\ (24\ \text{hr/day})}{\text{Flow, gal/day}}$$

DEWATER **DEWATER**

(1) To remove or separate a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of.

(2) To remove or drain the water from a tank or a trench.

DIRECT FILTRATION **DIRECT FILTRATION**

A method of treating water which consists of the addition of coagulation chemicals, flash mixing, coagulation, minimal flocculation and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted.

EFFLUENT (EF-loo-ent) **EFFLUENT**

Water or other liquid — raw, partially or completely treated — flowing *FROM* a reservoir, basin, treatment process or treatment plant.

INFLUENT (IN-flu-ent) **INFLUENT**

Water or other liquid — raw or partially treated — flowing *INTO* a reservoir, basin, treatment process or treatment plant.

LAUNDERS (LAWN-ders) LAUNDERS

Sedimentation basin and filter discharge channels, consisting of overflow weir plates (in sedimentation basins) and conveying troughs.

NONPOINT SOURCE NONPOINT SOURCE

A runoff or discharge from a field or similar source. A point source refers to a discharge that comes out the end of a pipe.

OVERFLOW RATE OVERFLOW RATE

One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called SURFACE LOADING.

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

PLUG FLOW PLUG FLOW

A type of flow that occurs in tanks, basins or reactors when a slug of water moves through a tank without ever dispersing or mixing with the rest of the water flowing through the tank.

POINT SOURCE POINT SOURCE

A discharge that comes out the end of a pipe. A nonpoint source refers to runoff or a discharge from a field or similar source.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

SEDIMENTATION (SED-uh-men-TAY-shun) SEDIMENTATION

A water treatment process in which solid particles settle out of the water being treated in a large clarifier or sedimentation basin.

SEPTIC (SEP-tick) SEPTIC

A condition produced by bacteria when all oxygen supplies are depleted. If severe, bottom deposits and water turn black, give off foul odors, and the water has a greatly increased chlorine demand.

SHOCK LOAD SHOCK LOAD

The arrival at a water treatment plant of raw water containing unusual amounts of algae, colloidal matter, color, suspended solids, turbidity, or other pollutants.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

SLURRY (SLUR-e) SLURRY

A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and water surface of a basin or container.

SURFACE LOADING SURFACE LOADING

One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called OVERFLOW RATE.

$$\text{Surface Loading, GPD/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

TUBE SETTLER TUBE SETTLER

A device which uses bundles of small bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. The tubes may come in a variety of shapes including circular and rectangular. As water rises within the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tube and settles to the bottom of the basin for removal by conventional sludge collection means. Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve particle removal.

TURBIDITY UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

VISCOSITY (vis-KOSS-uh-tee) VISCOSITY

A property of water, or any other fluid, which resists efforts to change its shape or flow. Syrup is more viscous (has a higher viscosity) than water. The viscosity of water increases significantly as temperatures decrease. Motor oil is rated by how thick (viscous) it is; 20 weight oil is considered relatively thin while 50 weight oil is relatively thick or viscous.

Chapter 5. SEDIMENTATION

(Lesson 1 of 2 Lessons)

5.0 PROCESS DESCRIPTION

5.00 Process Definition (Figure 5.1)

The purposes of the sedimentation process are to remove suspended solids (particles) that are denser (heavier) than water and to reduce the load on the filters (Chapter 6). The suspended solids may be in their natural state (such as bacteria, clays, or silts); they may be modified (preconditioned) by prior treatment in the coagulation-flocculation process (to form floc) or may be *PRECIPITATED*[1] impurities (hardness and iron precipitates formed by the addition of chemicals).

Sedimentation is accomplished or helped by decreasing the velocity of the water being treated below the point where it can transport settleable suspended material, thus allowing gravitational forces to remove particles held in suspension. When water is almost still in sedimentation basins, settleable solids will move towards the bottom of the basin.

5.01 Presedimentation

In Chapters 3 and 4, you learned that settling of larger-sized particles occurs naturally when surface water is stored for a sufficient period of time in a reservoir or a natural lake. Gravitational forces acting in the lake accomplish the same purpose as sedimentation in the water treatment plants; larger particles such as sand and heavy silts settle to the bottom.

Debris dams, grit basins or sand traps can also be used to remove some of the heavier particles from the source water. These facilities may be located upstream from the reservoir, diversion works or treatment plant intake or diversion facilities, and serve to protect the municipal intake pipeline from siltation (settling out of solids). Grit basins may be located between the intake structure and the coagulation-flocculation facilities (Fig. 5.2). Thus, presedimentation facilities such as debris dams, impoundments and grit basins reduce the solids-removal load at the water treatment plant. At the same time, they provide an equalizing basin which evens out fluctuations in the concentration of suspended solids in the source water.

Presedimentation facilities are often installed in locations where the source water supply is diverted directly from rivers or streams which can be contaminated by overland runoff and *POINT SOURCE*[2] waste discharges. Ideally, surface waters should be stored in a reservoir and transported directly to the water treatment plant in a pipeline. In a reservoir the heavier solids can settle out before they reach the plant. However, geographical, physical, and economic considerations (such as the lack of a suitable dam site) often make this alternative impractical.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 188.

5.0A What are the purposes of the sedimentation process?

5.0B How is sedimentation accomplished?

5.0C Presedimentation facilities are installed in what types of locations?

5.1 PROCESS PERFORMANCE CONSIDERATIONS

5.10 Factors Affecting Sedimentation

The size, shape and weight of the particles to be settled out, as well as physical and environmental conditions in the sedimentation tank, have a significant impact on the type of pretreatment needed and the sedimentation process efficiency.

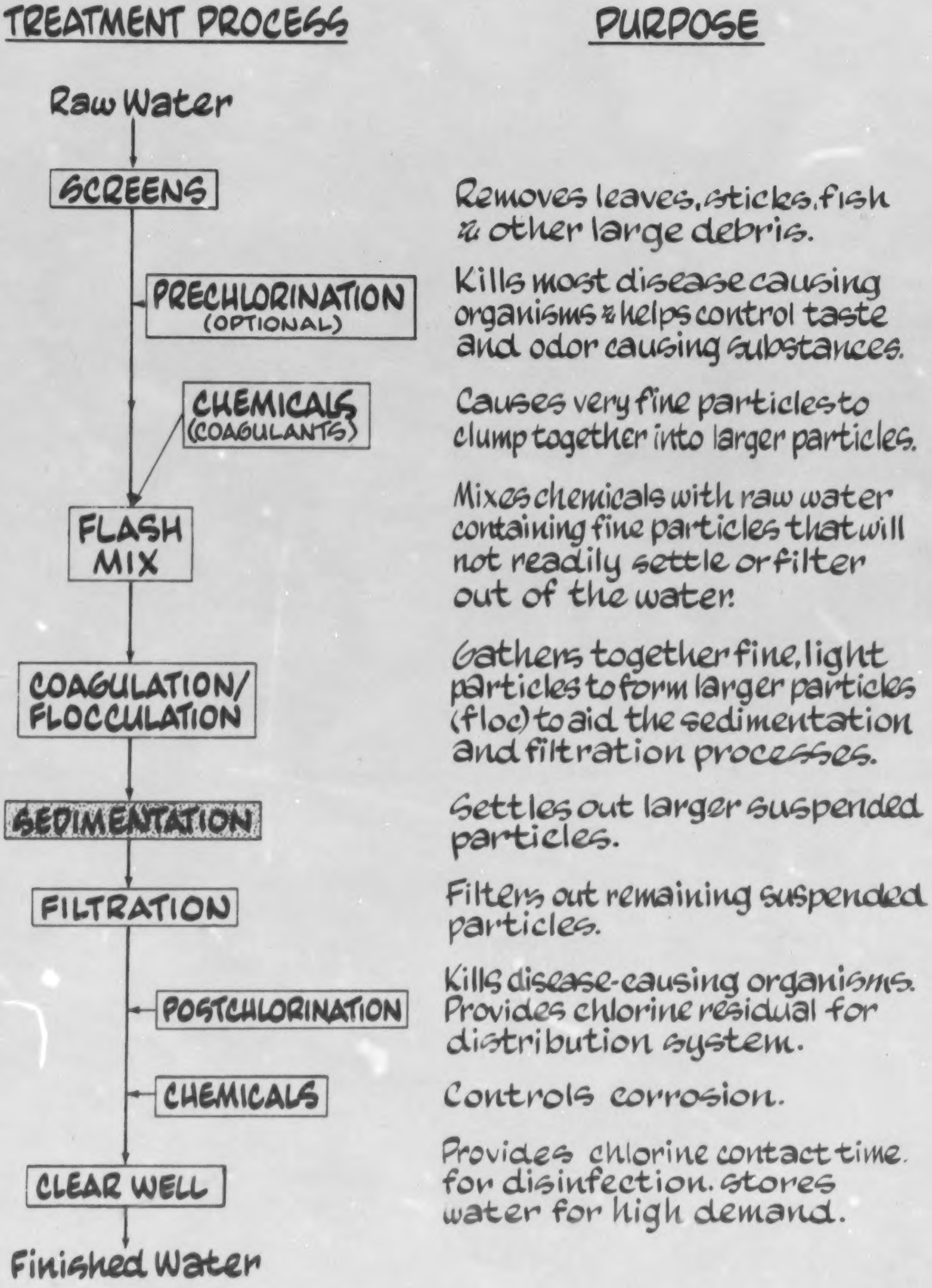
Factors affecting particle settling include:

1. Particle size and distribution,
2. Shape of particles,
3. Density of particles,

---

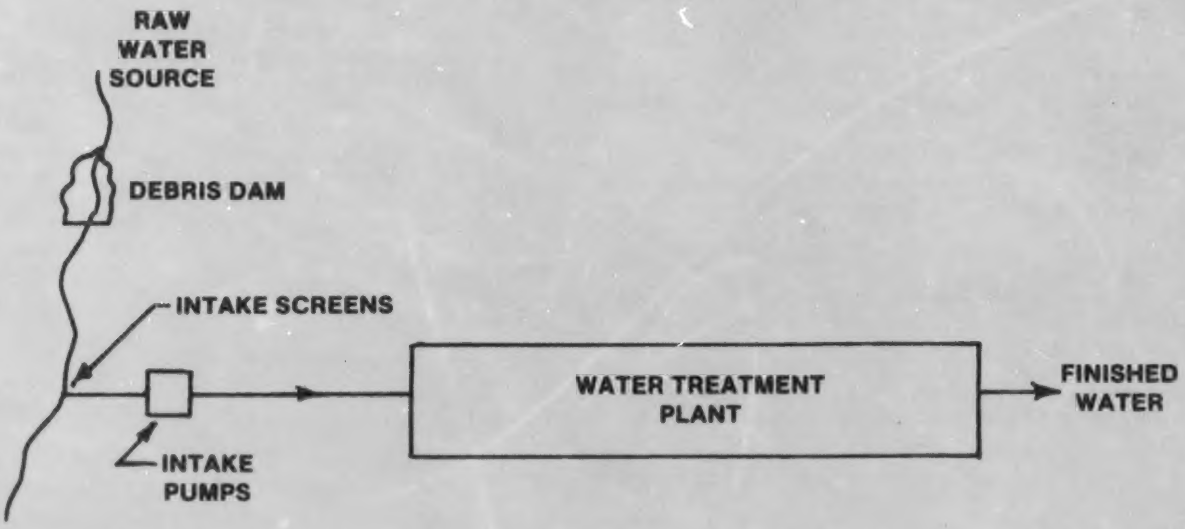
[1] *Precipitate (pre-SIP-uh-TATE). (1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid. (2) The separation from solution of an insoluble substance.*

[2] *Point Source. A discharge that comes out the end of a pipe. A nonpoint source refers to runoff or a discharge from a field or similar source.*



TREATMENT PROCESS	PURPOSE
SCREENS	Removes leaves, sticks, fish & other large debris.
PRECHLORINATION (OPTIONAL)	Kills most disease causing organisms & helps control taste and odor causing substances.
CHEMICALS (COAGULANTS)	Causes very fine particles to clump together into larger particles.
FLASH MIX	Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water.
COAGULATION/ FLOCCULATION	Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration processes.
SEDIMENTATION	Settles out larger suspended particles.
FILTRATION	Filters out remaining suspended particles.
POSTCHLORINATION	Kills disease-causing organisms. Provides chlorine residual for distribution system.
CHEMICALS	Controls corrosion.
CLEAR WELL	Provides chlorine contact time. for disinfection. stores water for high demand.

Fig. 5.1 Flow diagram of typical plant


RAW
WATER
SOURCE
DEBRIS DAM
INTAKE SCREENS
INTAKE
PUMPS
WATER TREATMENT
PLANT
FINISHED
WATER

DEBRIS DAM

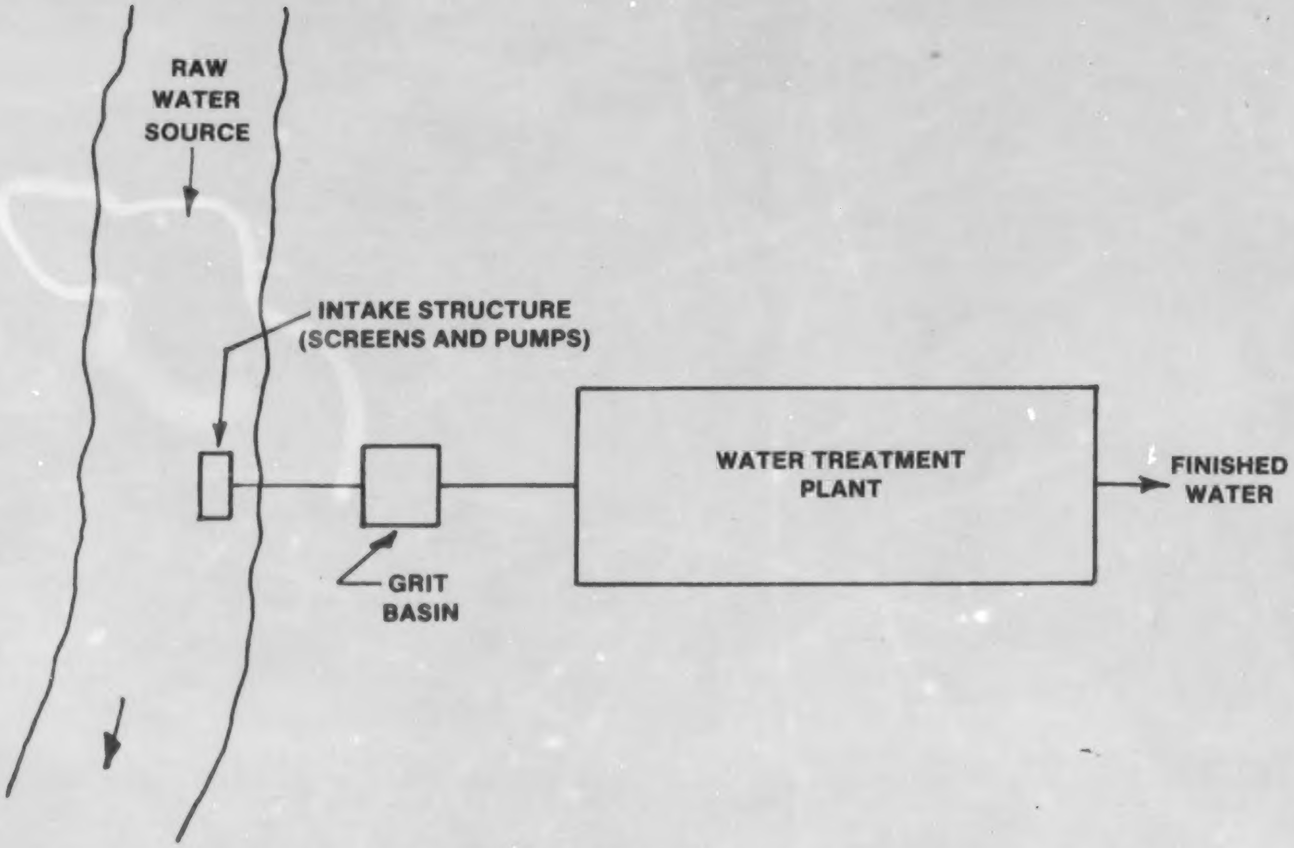

RAW
WATER
SOURCE
INTAKE STRUCTURE
(SCREENS AND PUMPS)
GRIT
BASIN
WATER TREATMENT
PLANT
FINISHED
WATER

Fig. 5.2 Presedimentation facilities

4. Temperature (*VISCOSITY*[3] and *DENSITY*[4]) of water,
5. Electrical charge on particles,
6. Dissolved substances in water,
7. Flocculation characteristics of the suspended material,
8. Environmental conditions (such as wind effects), and
9. Sedimentation basin hydraulic and design characteristics (such as inlet conditions and shape of basin).

5.11 Nature of Particulate Impurities

Because of their size and density, sand and silt particles greater than 10 microns in diameter (1 micron = 0.001 mm) can be removed from water by sedimentation (simple gravitational settling). In contrast, finer particles do not readily settle and treatment is required to produce larger, denser particles (floc) that are settleable (see Table 5.1).

TABLE 5.1 TYPICAL SIZE OF PARTICLES IN SURFACE WATERS

SOURCE	DIAMETER OF PARTICLE (microns)[a]
Coarse Turbidity	1 - 1000
Algae	3 - 1000
Silt	10
Bacteria	0.3 - 10
Fine Turbidity	0.1 - 1
Viruses	0.02 - 0.26
Colloids	0.001 - 1

[a] 1 micron = 0.00004 of an inch

The shape of particles influences particle settling also. Smooth circular particles will settle quicker than irregular-shaped particles with ragged edges.

Most particles have a very slight electrical charge. If all of the particles have a negative charge, they will tend to repel each other and not settle. Since alum consists of aluminum with a positive charge, the negatively charged particles are attracted to the positively charged aluminum ions. This causes the clumping together which helps the particles to settle out.

5.12 Water Temperature

Another consideration in sedimentation is the effect of water temperature changes. The settling rate (settling velocity) of a particle becomes much slower as the temperature drops. The colder the water temperature becomes, the longer particles take to settle out. Water acts similar to syrup in this regard. The colder syrup becomes, the longer it would take a marble to settle to the bottom of the container. This means that longer time periods (lower flows) are required for effective settling at colder water temperatures, or that chemical dosages must be adjusted for the slower settling velocities.

5.13 Currents

Several types of currents are found in the typical sedimentation basin:

1. Surface currents caused by winds,
2. Density currents caused by differences in suspended solids concentrations and temperature differences, and
3. Eddy current produced by the flow of the water coming into and leaving the basin.

Currents in the sedimentation basin are beneficial to the extent that they promote flocculation. Collectively, however, these currents distribute the suspended particles unevenly throughout the basin, thereby reducing the expected performance of the sedimentation basin.

Some of these currents can be substantially reduced in the design of a treatment plant by providing baffled inlets and other hydraulic control features (described in a later section). Others, such as wind-induced currents, can only be eliminated by providing covers or suitable windbreaks for the sedimentation basins. In most instances, basin covers are not economically feasible nor necessarily desirable from an operations and maintenance standpoint.

5.14 Particle Interactions

Suspended particles will continue to clump together (form floc) and other particles will precipitate from solution through flocculation and chemical precipitation in the sedimentation basin. The density and volume of particles will change. As a result, the settling velocities of individual particles will change as larger, denser floc particles are formed when particles of different size and density collide during the sedimentation process. Generally, this results in increased settling velocities.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 188.

5.1A List as many factors as you can recall which affect particle settling in a sedimentation basin.

5.1B Why is treatment preferred before sedimentation?

5.1C What types of currents may be found in a typical sedimentation basin?

---

[3] *Viscosity (vis-KOS-uh-tee). A property of water, or any other fluid, which resists efforts to change its shape or flow. Syrup is more viscous (has a higher viscosity) than water. The viscosity of water increases significantly as temperatures decrease. Motor oil is rated by how thick (viscous) it is; 20 weight oil is considered relatively thin while 50 weight oil is relatively thick or viscous.*

[4] *Density (DEN-sit-tee). A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic foot. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.*

5.2 SEDIMENTATION BASINS

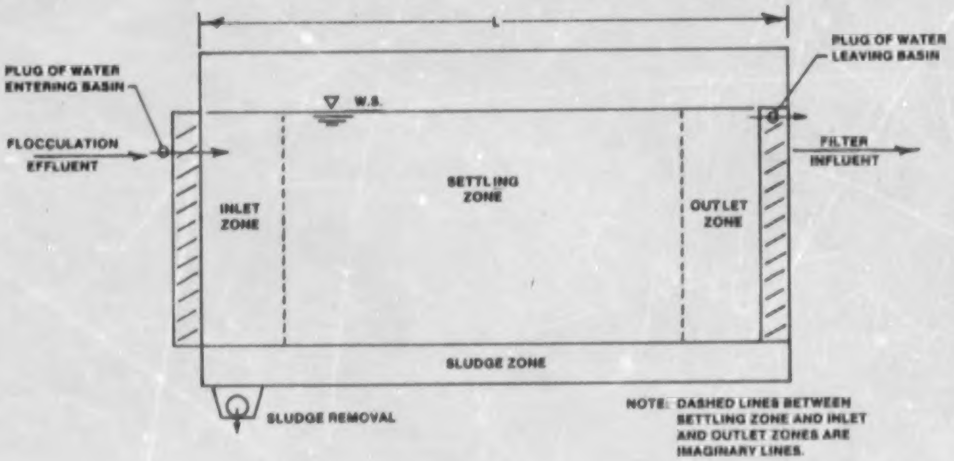
5.20 Sedimentation Basin Zones

For convenience in discussing sedimentation basins, a typical sedimentation basin can be divided into four zones (see Figure 5.3):

1. Inlet zone,
2. Settling zone,
3. Sludge zone, and
4. Outlet zone.

5.200 Inlet Zone

The inlet to the sedimentation basin should provide a smooth transition from the flocculation basin and should distribute the flocculated water uniformly over the entire cross-section of the basin. A properly designed inlet such as a perforated baffle wall (see Figures 5.4 and 5.5), will significantly reduce *SHORT-CIRCUITING*[5] of water in the basin, and will minimize the effects of the water wanting to flow at the inlet velocity straight through the basin, density flow (results from temperature differences), and wind currents, as previously described.


L
PLUG OF WATER ENTERING BASIN
FLOCCULATION EFFLUENT
W.S.
PLUG OF WATER LEAVING BASIN
FILTER INFLUENT
INLET ZONE
SETTLING ZONE
OUTLET ZONE
SLUDGE ZONE
SLUDGE REMOVAL

NOTE: DASHED LINES BETWEEN SETTLING ZONE AND INLET AND OUTLET ZONES ARE IMAGINARY LINES.

Fig. 5.3 Sedimentation basin zones

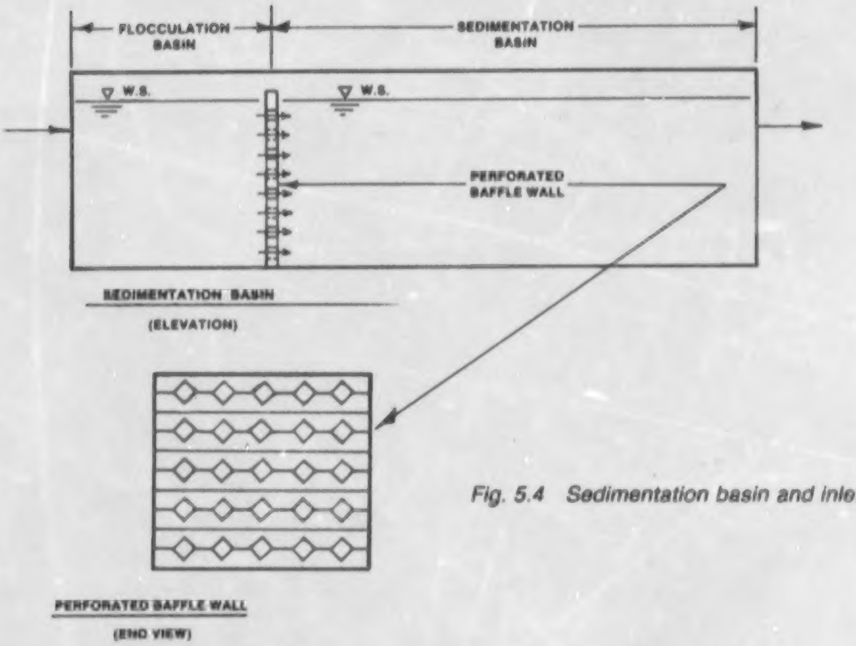

FLOCCULATION BASIN
SEDIMENTATION BASIN
W.S.
W.S.
PERFORATED BAFFLE WALL
SEDIMENTATION BASIN
(ELEVATION)
PERFORATED BAFFLE WALL
(END VIEW)

Fig. 5.4 Sedimentation basin and inlet baffle wall

---

[5] *Short-circuiting. A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.*

5.201 Settling Zone

The settling zone is the largest portion of the sedimentation basin. This zone provides calm, undisturbed storage of the flocculated water for a sufficient time period (three or more hours) to permit effective settling of the suspended particles in the water being treated.

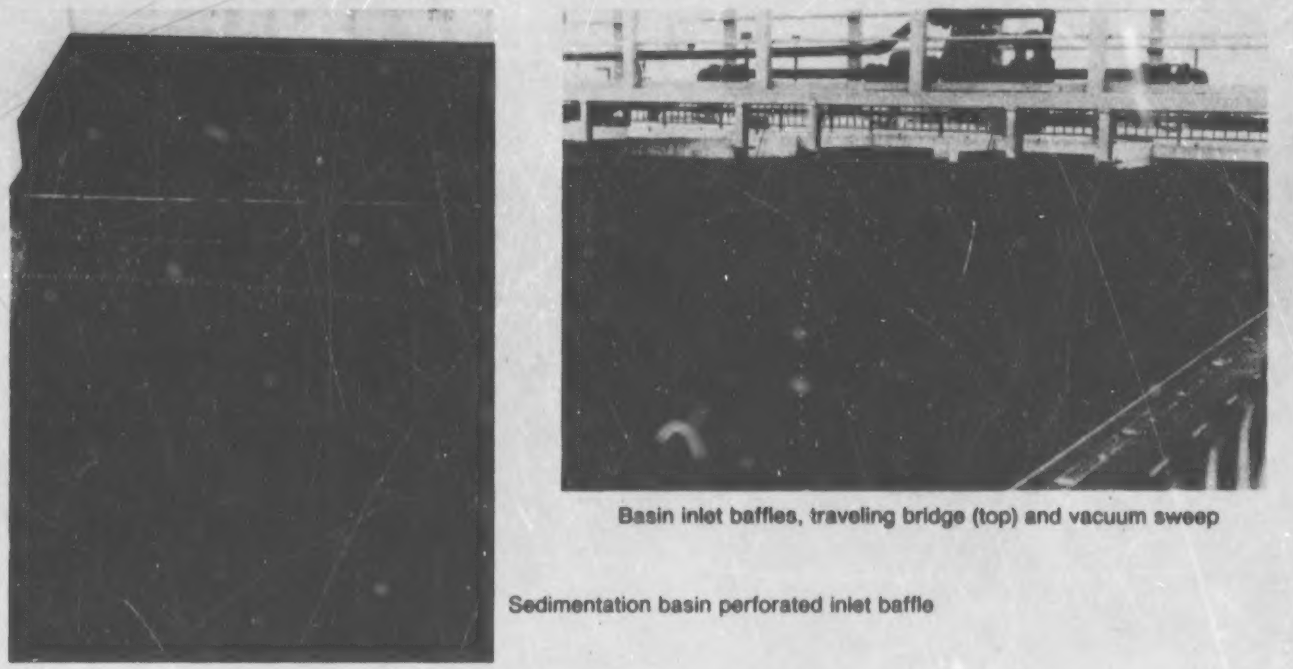
SETTLING ZONE
SLUDGE ZONE

5.202 Sludge Zone

The sludge zone is located at the bottom of the sedimentation basin and is a temporary storage place for the settled particles (Fig. 5.6). Also the sludge zone is used to allow for compression settling (sludge settling on to zone compacts lower sludge) of the sludge.

Basin inlet structures should be designed to minimize high flow velocities near the bottom of the sedimentation basin, which could disturb or *SCOUR* settled particles in the sludge zone, causing them to become resuspended.

Sludge is removed from the sludge zone by scraper and vacuum devices which move along the bottom of the sedimentation basin (Figures 5.7 and 5.8) as necessary or on a

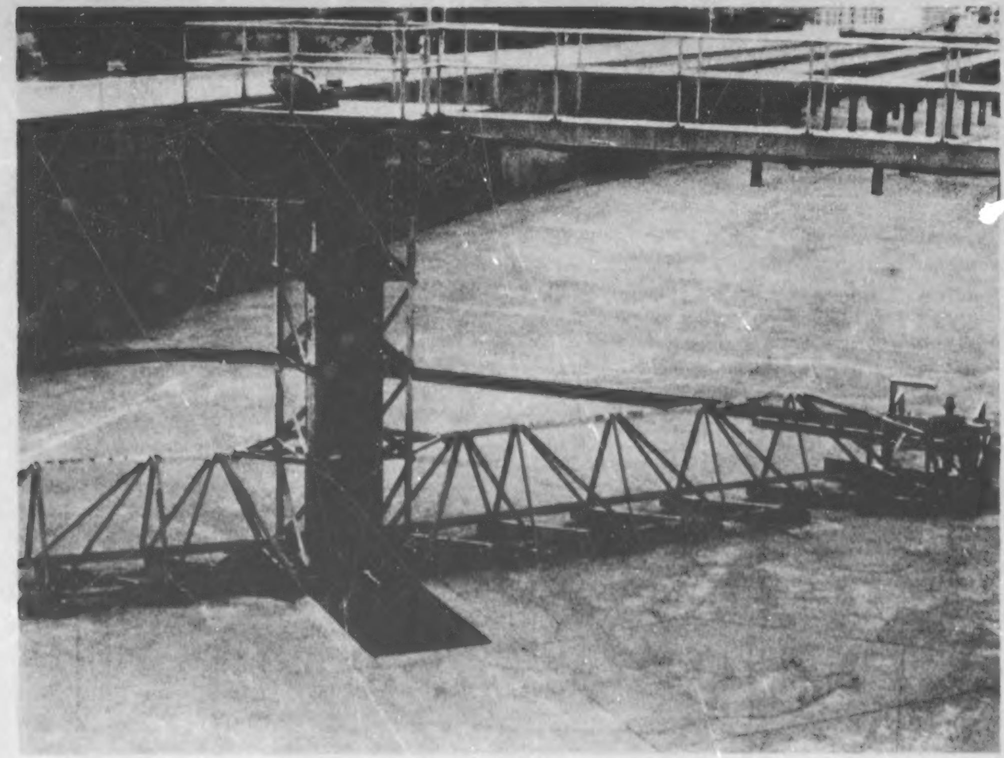


Basin inlet baffles, traveling bridge (top) and vacuum sweep

Sedimentation basin perforated inlet baffle

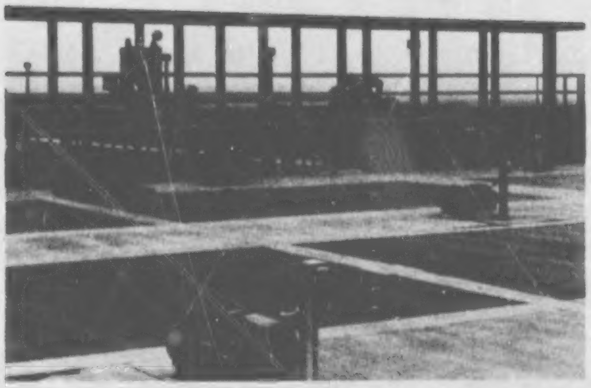
Fig. 5.5 Sedimentation basin perforated inlet baffle

Fig. 5.6 Sludge buildup in bottom of sedimentation basin



NOTE: Sludge sump is hole in middle.

Fig. 5.7 Sludge scraper



Traveling bridge (top) sludge removal system
(Note covered flocculators in foreground)

Traveling bridge vacuum sweep (sweep at bottom)

Fig. 5.8 Vacuum sweep sludge removal system

regularly scheduled basis. Some plants require that the basin be drained and flushed to remove the sludge if the removal devices do not operate over the entire length of the basin.

5.203 Outlet Zone

The basin outlet should provide a smooth transition from the sedimentation basin to the settled water conduit or channel. The outlet can also control the water level in the basin.

Skimming or effluent troughs, commonly referred to as *LAUNDERS* (Figures 5.9, 5.10, 5.11 and 5.12), are frequently used to uniformly collect the settled or clarified water. Adjustable V-notch weirs (Figures 5.11 and 5.12) are generally attached to the launders to enable a uniform draw-off of basin water by controlling the flow. If the water leaving a sedimentation basin flows out unevenly over the weirs or at too high a velocity, floc can be carried over to the filters.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 189.

5.2A List the four zones into which a typical sedimentation basin can be divided.

5.2B What is the purpose of the settling zone in a sedimentation basin?

5.2C What are launders?

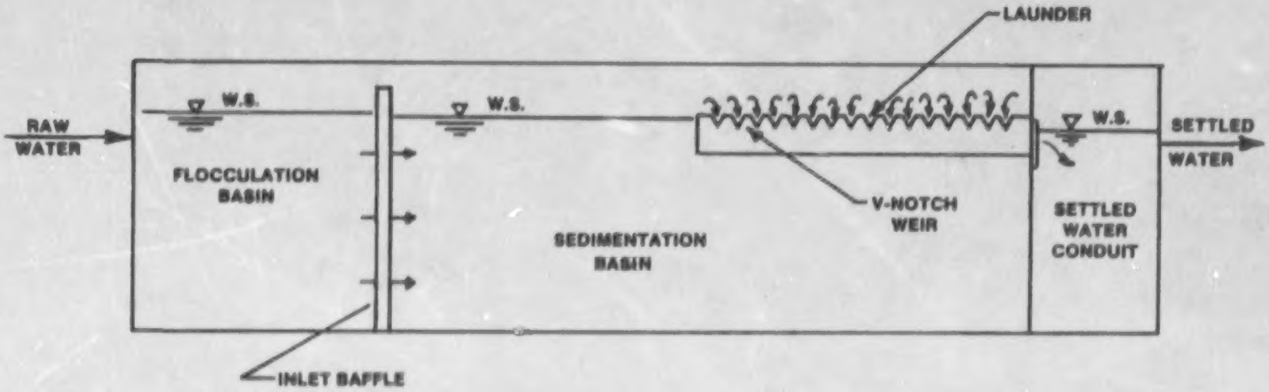


Fig. 5.9 Typical sedimentation basin outlet (flow over V-notch weirs)

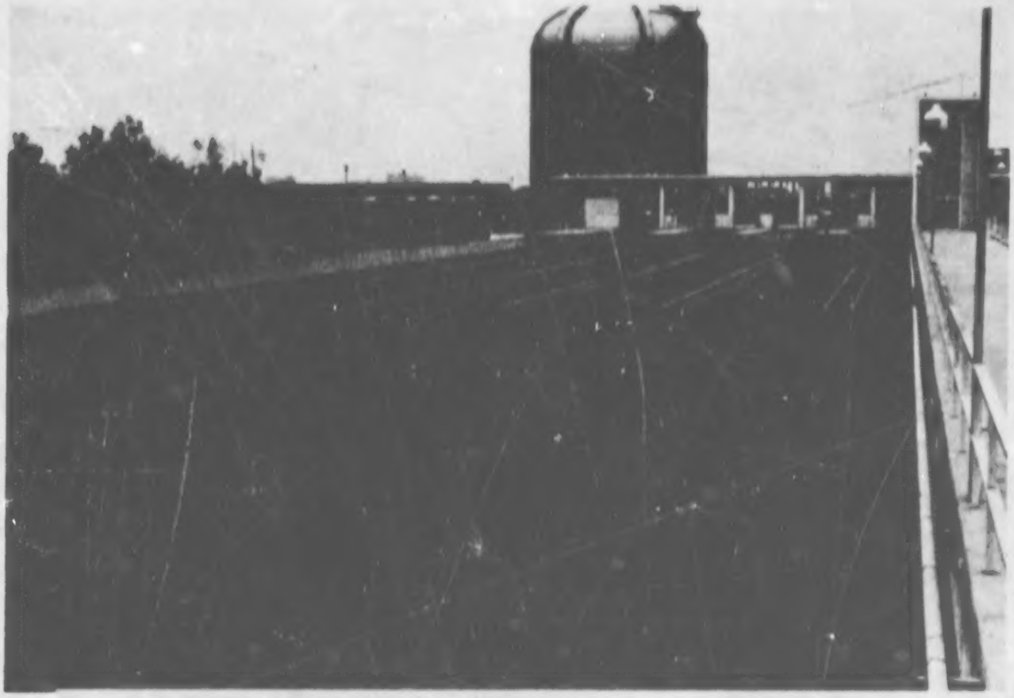
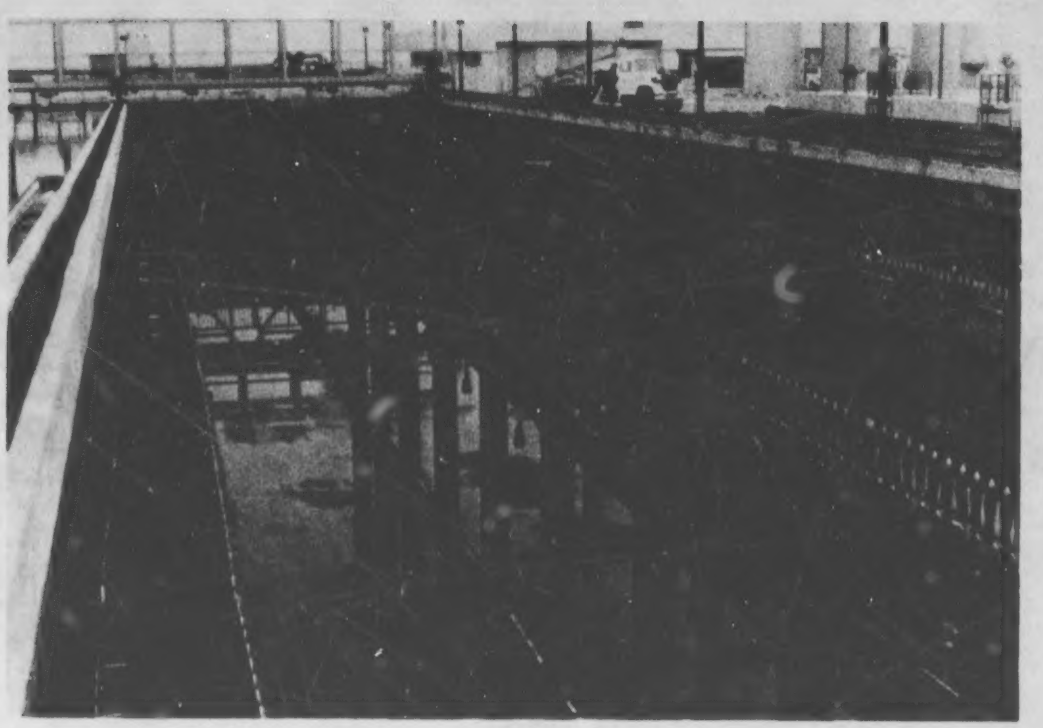
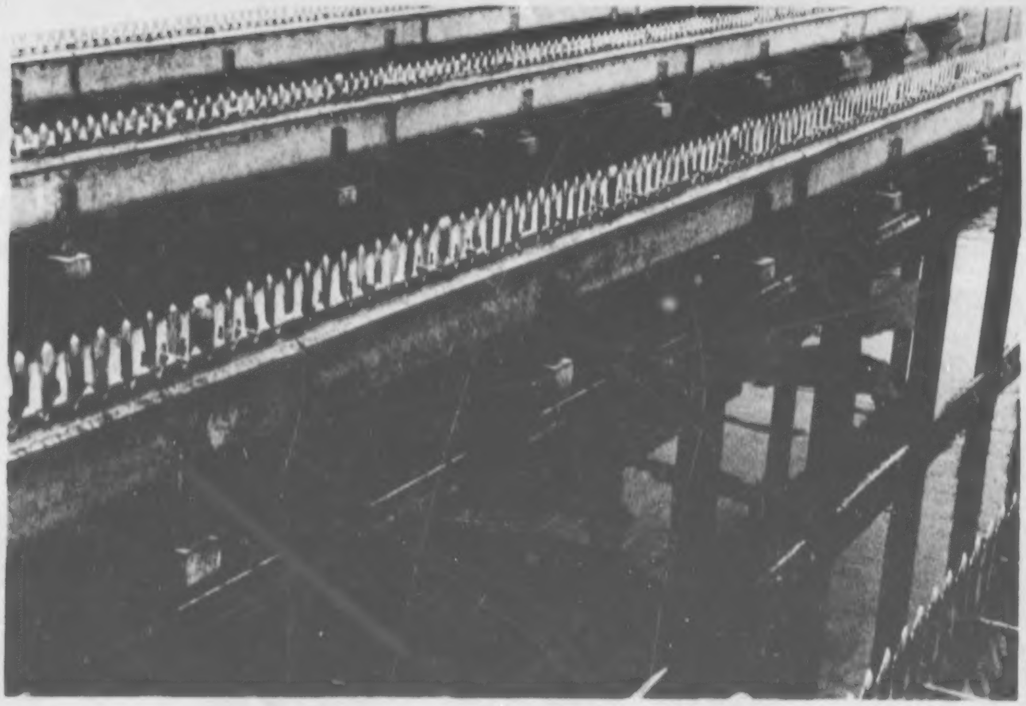


Fig. 5.10 Effluent launders in empty sedimentation basin

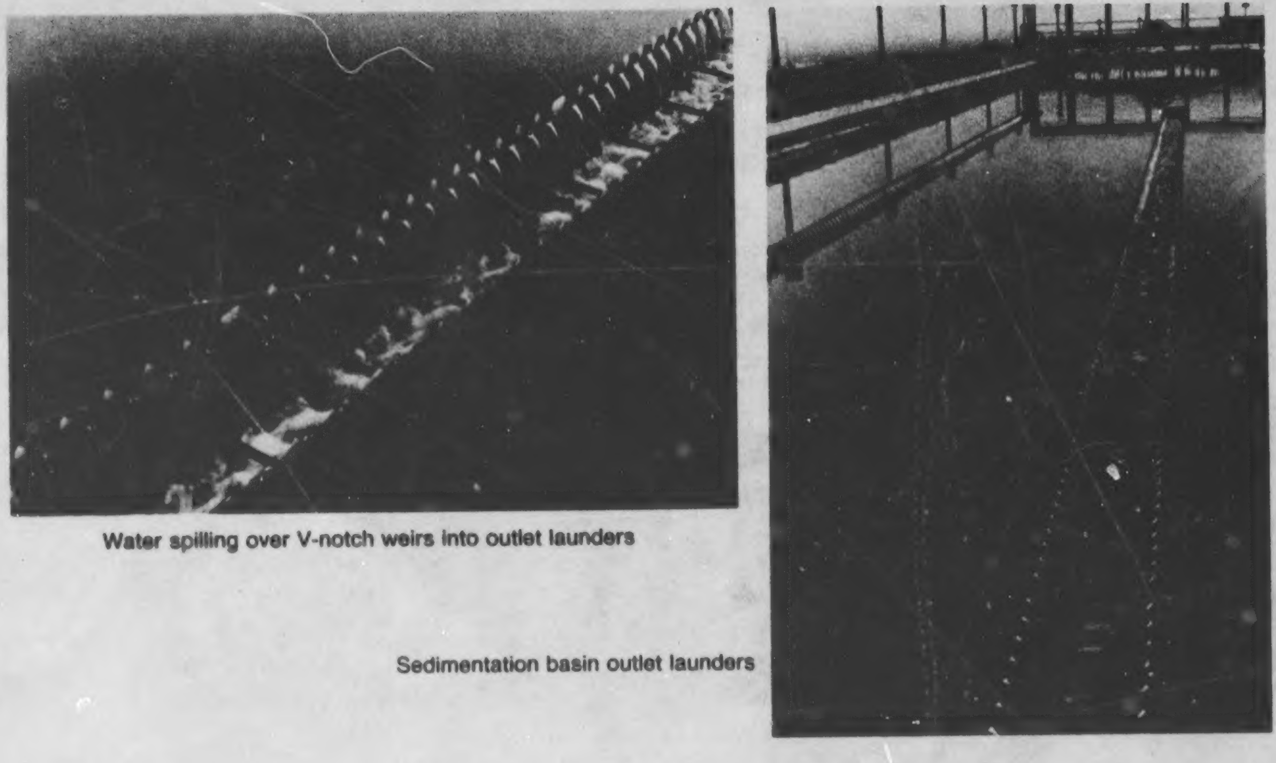


Dewatered sedimentation basin
(Note inlet baffle at far end and traveling bridge above baffle)



Sedimentation basin outlet launders and V-notch weirs

Fig. 5.11 Empty sedimentation basin



Water spilling over V-notch weirs into outlet launders

Sedimentation basin outlet launders

Fig. 5.12 Sedimentation basin outlet launders and V-notch weirs

5.21 Basin Types

BASIN
ECONOMY
SIZE
JUST
ADD
WATER

5.210 Selection of Basin Type

There are a wide variety of basin types and configurations in use today (Figure 5.13). The more common basin types will be described in the following sections to acquaint you with the major characteristics of each style.

5.211 Rectangular Basins

Rectangular sedimentation basins are commonly found in many large-scale water treatment plants. Rectangular basins are popular for the following reasons:

1. High tolerance to *SHOCK LOADING*[6] (water quality changes),
2. Predictable performance,
3. Cost-effectiveness,
4. Low maintenance, and
5. Minimal short-circuiting.

5.212 Double-Deck Basins

Double-deck basins (see Figure 5.14) are an adaptation of the rectangular basin design. By stacking one basin on top of another, double-deck basins provide twice the effective sedimentation surface area of a single basin of equivalent land area. Double-deck basins are designed to conserve land area, but are not in common use owing partially to higher operation and maintenance costs. In this design, sludge removal equipment must operate in both decks, and the entire operation may have to be shut down if an equipment problem develops in either deck.

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[6] *Shock Load. The arrival at a water treatment plant of raw water containing unusual amounts of algae, colloidal matter, color, suspended solids, turbidity, or other pollutants.*

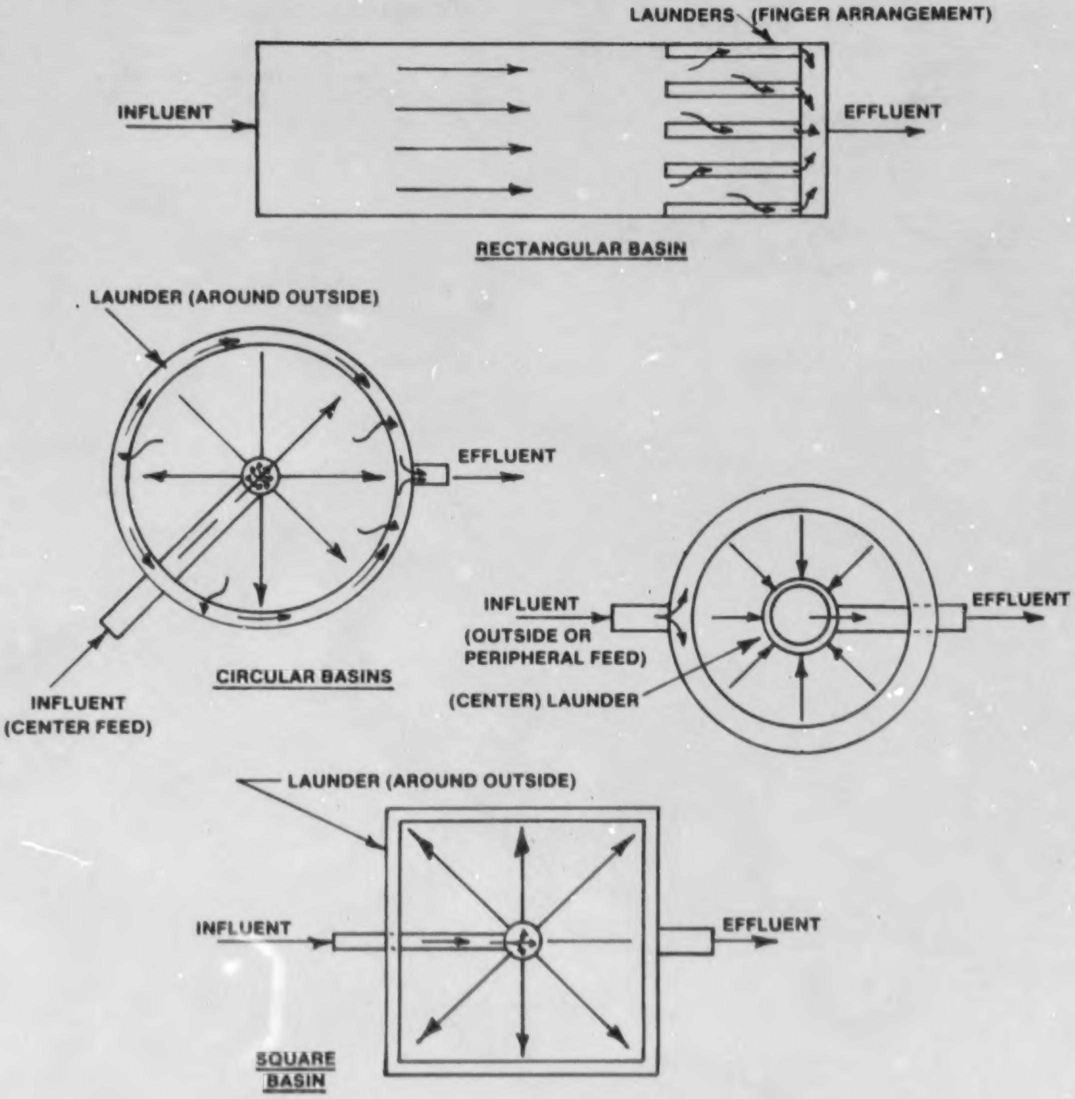

LAUNDERS (FINGER ARRANGEMENT)
INFLUENT
EFFLUENT
RECTANGULAR BASIN
LAUNDER (AROUND OUTSIDE)
EFFLUENT
CIRCULAR BASINS
INFLUENT
(CENTER FEED)
INFLUENT
(OUTSIDE OR
PERIPHERAL FEED)
(CENTER) LAUNDER
EFFLUENT
LAUNDER (AROUND OUTSIDE)
INFLUENT
EFFLUENT
SQUARE
BASIN

Fig. 5.13 Sedimentation basin types (plan views)

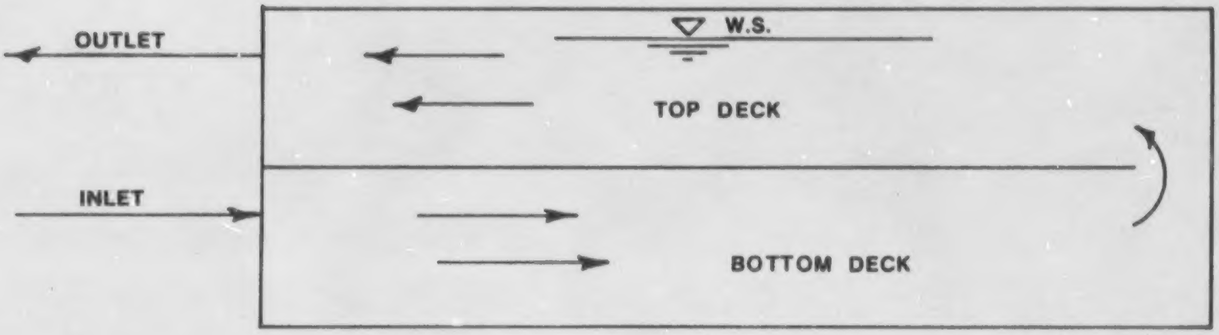

OUTLET
W.S.
TOP DECK
INLET
BOTTOM DECK

Fig. 5.14 Double-deck sedimentation basin (elevation)

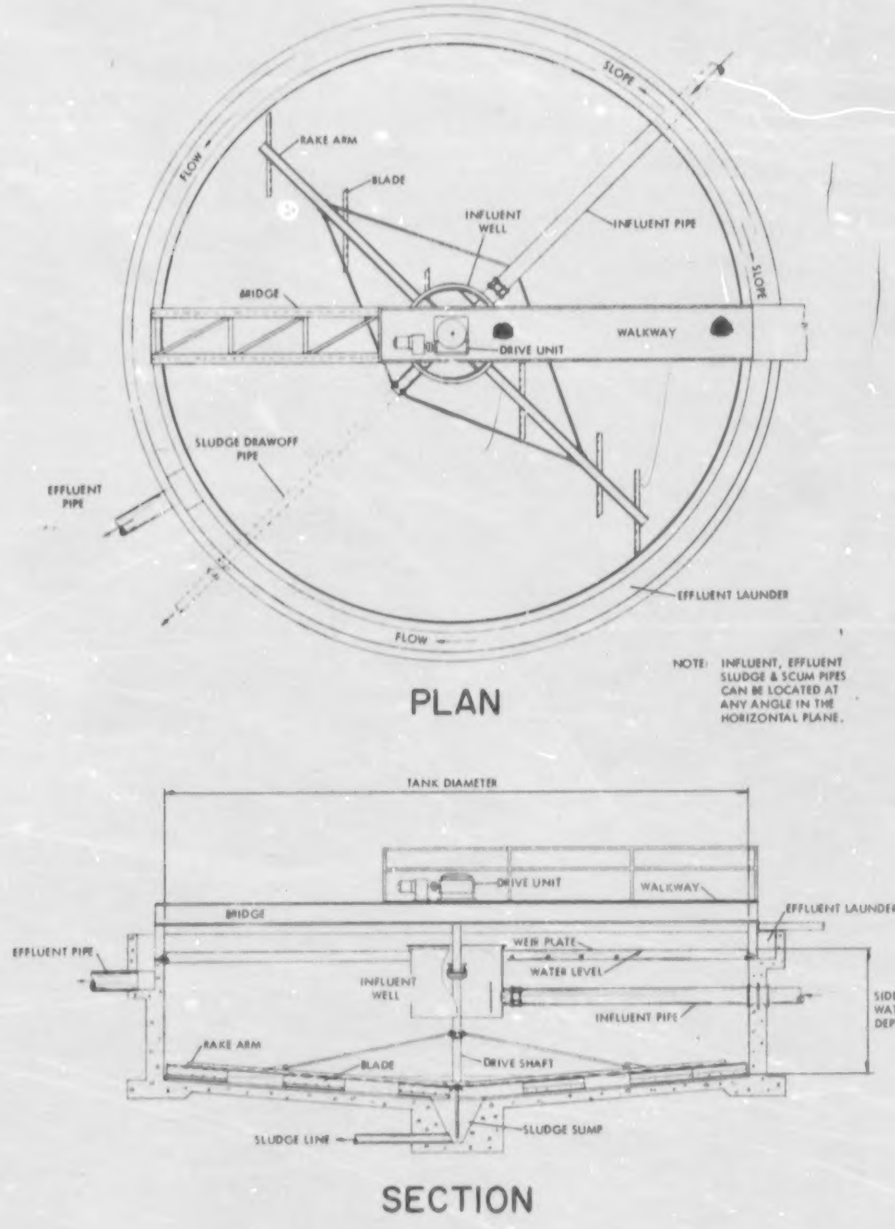
5.213 Circular and Square Basins

Circular or square, horizontal-flow basins, as shown in Figures 5.13, 5.15 and 5.16, are often referred to as *CLARIFIERS*. These basins share some of the performance advantages of rectangular basins; however, they are generally more likely to have short-circuiting and particle removal problems. One of the major problems with square settling basins is the removal of sludge from the corners. This can also be a problem with rectangular basins. Some circular clarifiers are also called solids-contact units or upflow clarifiers. These units are discussed in Section 5.215, "Solids-Contact Units."

5.214 High-Rate Settlers

High-rate or *TUBE SETTLERS* were developed to increase the settling efficiency of conventional rectangular sedimentation basins. They have been installed in circular basins with successful results.

Water enters the inclined settler tubes and is directed upward through the tubes as shown in Figures 5.17, 5.18 and 5.19. Each tube functions as a shallow settling basin. Together, they provide a high ratio of effective settling surface area per unit volume of water. The settled particles can collect on the inside surfaces of the tubes or settle to the bottom of the sedimentation basin.


SLOPE
RAKE ARM
FLOW
BLADE
INFLUENT WELL
INFLUENT PIPE
SLOPE
BRIDGE
WALKWAY
DRIVE UNIT
SLUDGE DRAWOFF PIPE
EFFLUENT PIPE
EFFLUENT LAUNDER
FLOW
PLAN
TANK DIAMETER
DRIVE UNIT
WALKWAY
BRIDGE
EFFLUENT LAUNDER
EFFLUENT PIPE
WEIR PLATE
WATER LEVEL
INFLUENT WELL
INFLUENT PIPE
SIDE WATER DEPTH
RAKE ARM
BLADE
DRIVE SHAFT
SLUDGE SUMP
SLUDGE LINE
SECTION

NOTE: INFLUENT, EFFLUENT SLUDGE & SCUM PIPES CAN BE LOCATED AT ANY ANGLE IN THE HORIZONTAL PLANE.

Fig. 5.15 Circular clarifier
(Permission of General Filter)

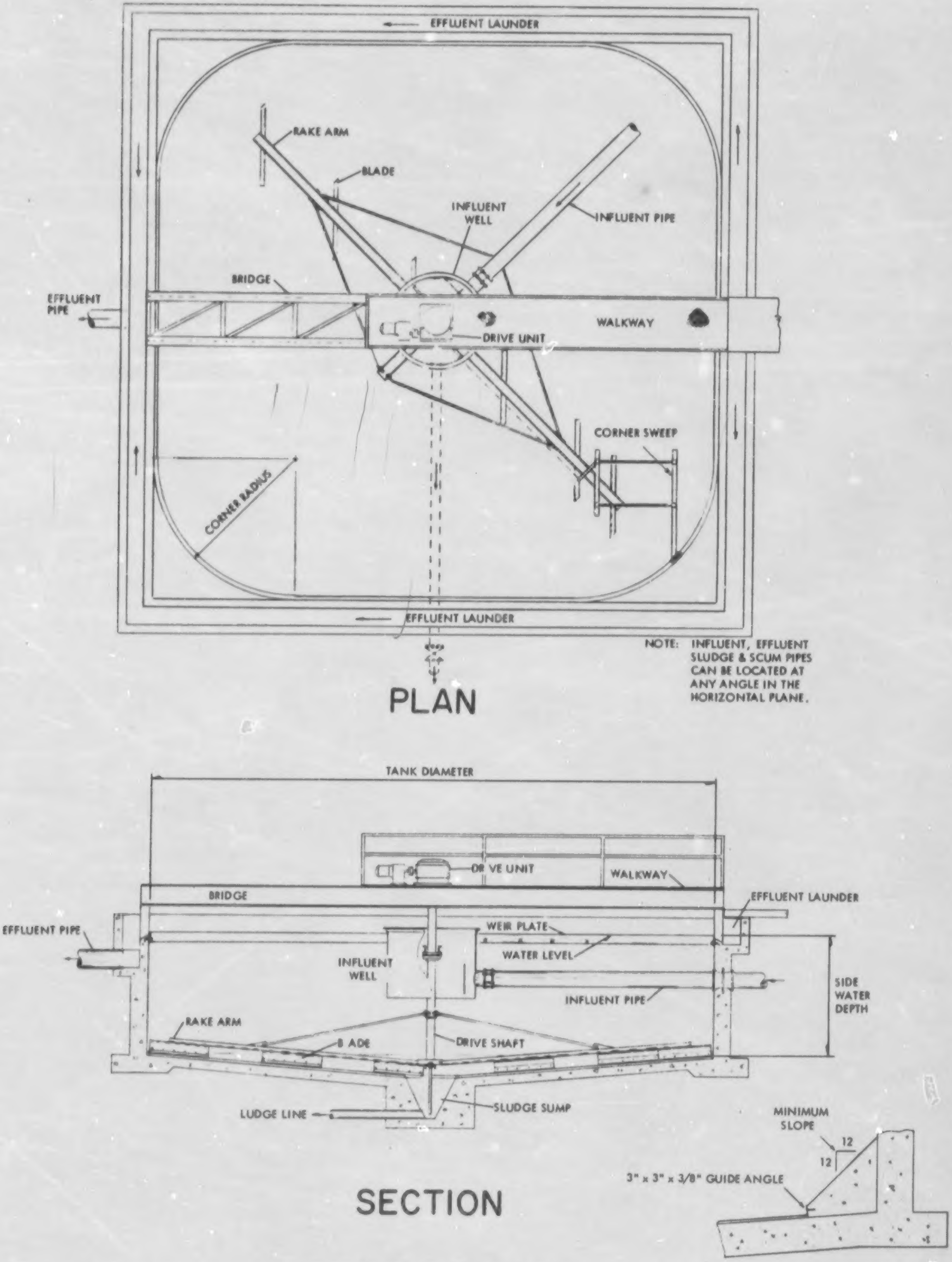

EFFLUENT LAUNDER
RAKE ARM
BLADE
INFLUENT WELL
INFLUENT PIPE
BRIDGE
EFFLUENT PIPE
WALKWAY
DRIVE UNIT
CORNER SWEEP
CORNER RADIUS
EFFLUENT LAUNDER
NOTE: INFLUENT, EFFLUENT SLUDGE & SCUM PIPES CAN BE LOCATED AT ANY ANGLE IN THE HORIZONTAL PLANE.
PLAN
TANK DIAMETER
DRIVE UNIT
WALKWAY
BRIDGE
EFFLUENT LAUNDER
EFFLUENT PIPE
WEIR PLATE
WATER LEVEL
INFLUENT WELL
INFLUENT PIPE
SIDE WATER DEPTH
RAKE ARM
BLADE
DRIVE SHAFT
SLUDGE LINE
SLUDGE SUMP
MINIMUM SLOPE
12
12
3" x 3" x 3/8" GUIDE ANGLE
SECTION

Fig. 5.16 Square clarifier basin

(Permission of General Filter)

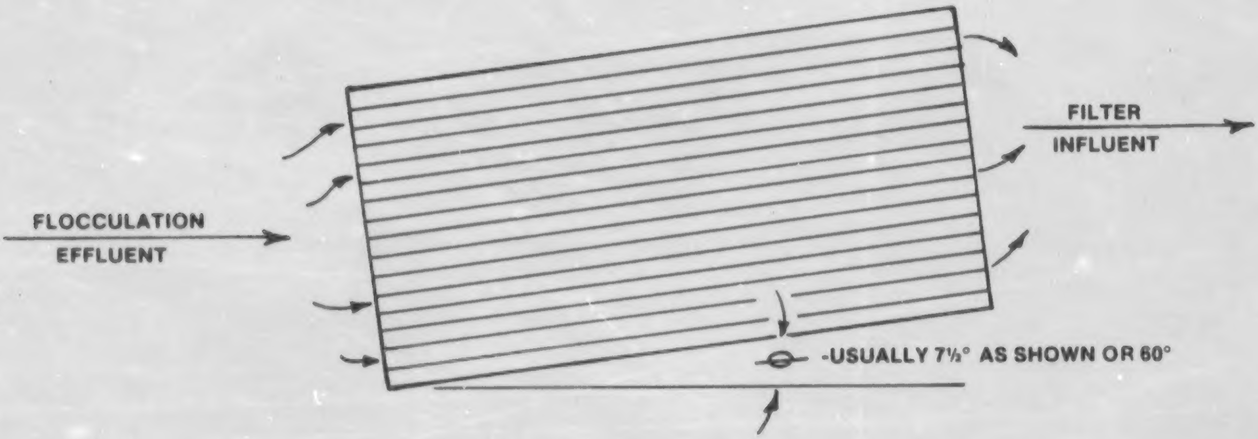
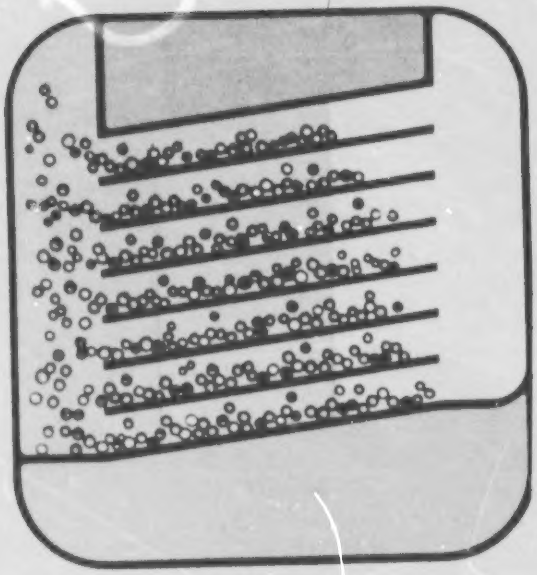
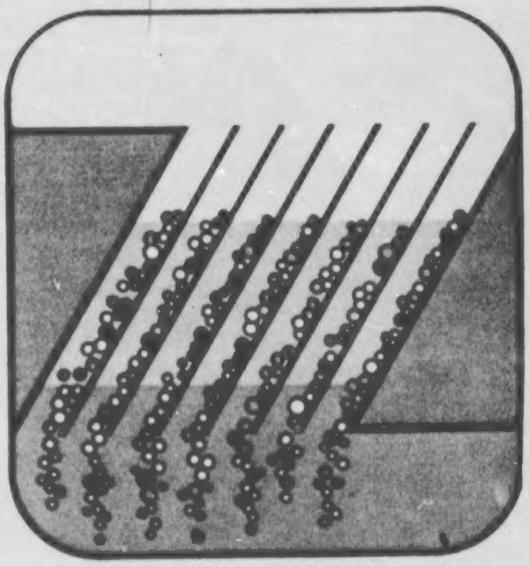

FLOCCULATION
EFFLUENT
FILTER
INFLUENT
-USUALLY 7½° AS SHOWN OR 60°

Fig. 5.17 Tube settler (installed in a rectangular or circular sedimentation basin)



7½° Tube Settlers



60° Tube Settlers

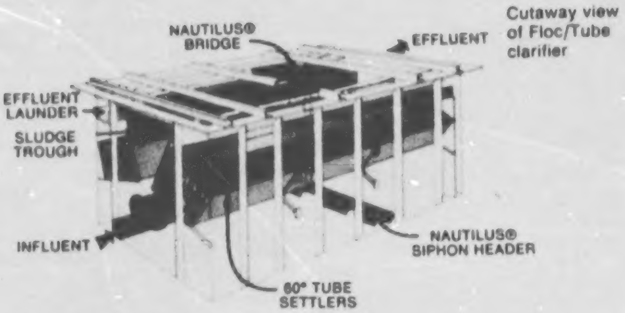

NAUTILUS®
BRIDGE
EFFLUENT
Cutaway view
of Floc/Tube
clarifier
EFFLUENT
LAUNDER
SLUDGE
TROUGH
INFLUENT
NAUTILUS®
SIPHON HEADER
60° TUBE
SETTLERS

Fig. 5.18 Cutaway view of Floc/Tube clarifier

(Permission of Neptune Microfloc, Inc.)

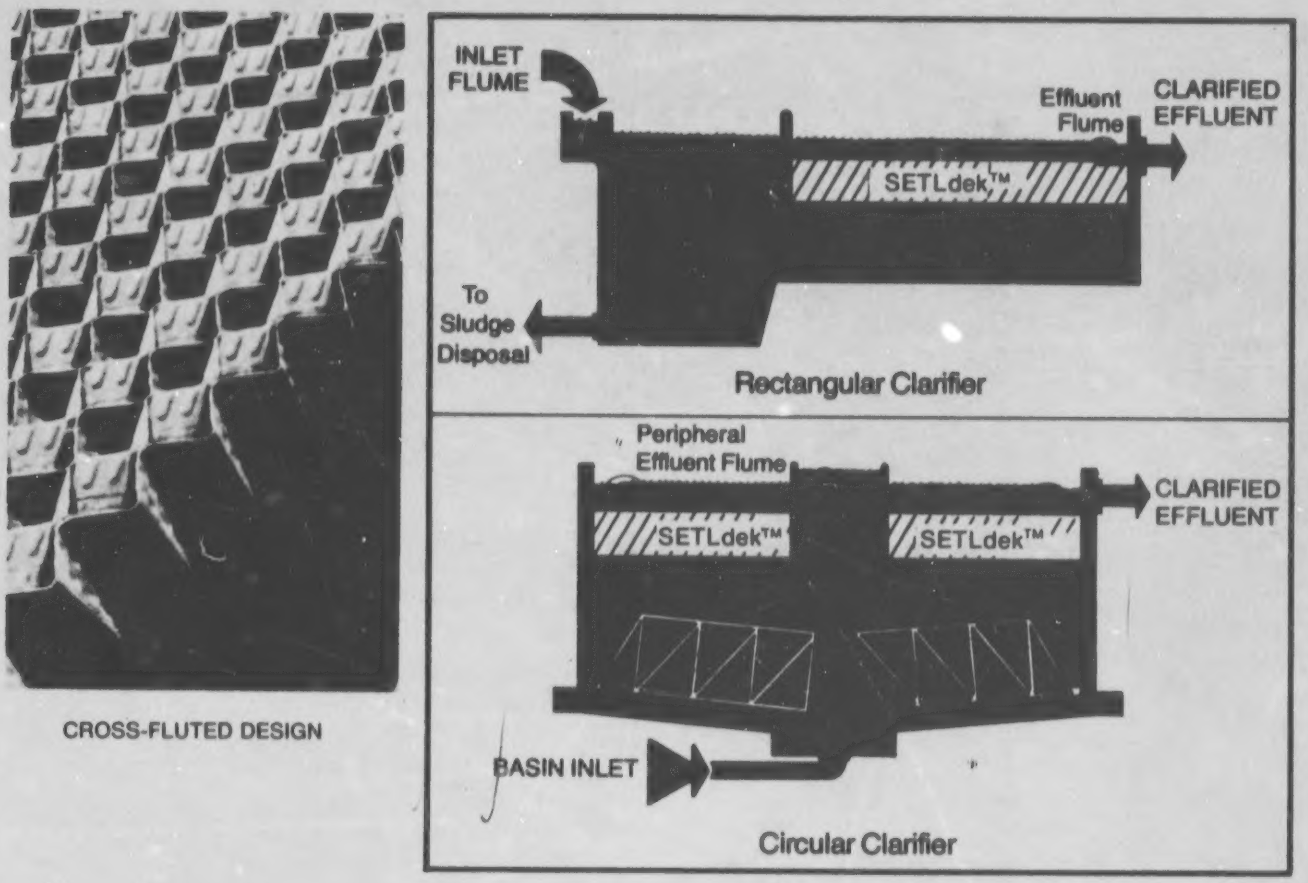

CROSS-FLUTED DESIGN

Fig. 5.19 Tube settlers in rectangular and circular clarifiers
(Permission of The Munters Corporation)

Parallel plate or tilted plate settlers can also be used to increase the efficiency of rectangular sedimentation basins, and these function in a manner similar to tube settlers.

High-rate settlers are particularly useful for water treatment applications where site area is limited, in packaged-type water treatment units, and to increase the capacity of existing sedimentation basins. In existing rectangular and circular sedimentation basins, high-rate settler modules can be conveniently installed between the launders. High winds can have an adverse effect on tube settlers.

5.215 Solids-Contact Units

The solids-contact process, also referred to as "up-flow solids-contact clarification" and "up-flow sludge-blanket clarification," was developed to improve the overall solids removal process under certain design conditions. These units combine the coagulation, flocculation, and sedimentation processes into a single basin, which may be either rectangular or circular in shape. Flow is generally in an upward direction through a sludge blanket or slurry of flocculated, suspended solids as shown in Figure 5.20.

Solids-contact units generally have provisions for controlled removal of solids so that the concentration of solids retained in the basin can be maintained at some desired level.

Solids-contact units are popular for smaller packaged-type water treatment plants and also in cold climates where the units have to be inside a building. However, care must be exercised in the operation of these units to assure that a uniform sludge blanket is formed, and is subsequently maintained throughout the solids removal process. The sludge blanket is sensitive to changes in water temperature. Temperature density currents tend to upset the sludge blanket. Loss of the sludge blanket will affect the performance of the filters. Other important operational factors include control of chemical dosage, mixing of chemicals and control of the sludge blanket.

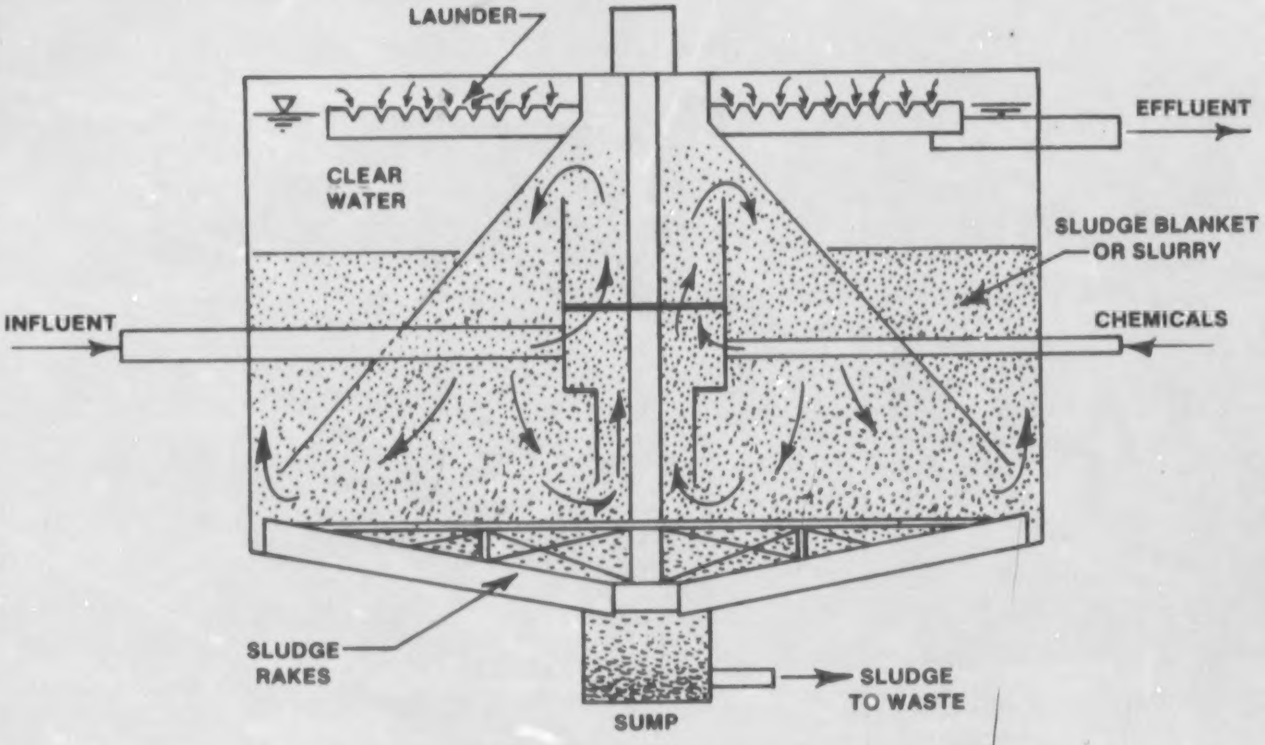


Fig. 5.20 Solids-contact unit

Under ideal conditions, solids-contact units provide better performance for both turbidity removal and softening processes requiring the precipitation of hardness. With softening processes, chemical requirements are usually lower also. In the case of turbidity removal, coagulant requirements are often higher. In either case, solids-contact units are very sensitive to changes in influent flow or temperature. In these facilities, changes in the rate of flow should be made infrequently, slowly, and with great care.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 189.

5.2D List three possible shapes for sedimentation basins.

5.2E List the advantages and limitations of double-deck sedimentation basins.

5.2F Why are rectangular sedimentation basins often preferred over circular basins?

5.2G During the operation of a solids-contact unit, what items should be of particular concern to the operator?

5.22 Basin Layout

A minimum of two sedimentation basins should be provided in all water treatment plants to provide for maintenance, cleaning, and inspection of a basin without requiring a complete plant shutdown.

A typical rectangular-shaped basin layout is shown in Figure 5.21. Note that a chemical application point is provided in the settled water conduit to permit feeding a filter aid chemical, chlorine, or other chemicals prior to filtration.

5.23 Detention Time

There are two definitions for detention time. Detention time (or retention time) is the actual time required for a small amount of water to pass through a sedimentation basin at a given rate of flow. Also, detention time can refer to the theoretical (calculated) time required for a small amount of water to pass through a basin at a given rate of flow. The detention time is calculated by dividing the volume of the basin by the flow going into the basin. Actual flow-through times for different small amounts of water in the same basin may vary significantly from the calculated detention time due to short-circuiting, effective exchangeable volume (portion of basin through which the water flows), and other hydraulic considerations such as basin inlet and outlet design. A dye placed at the inlet to a sedimentation basin will produce the curves shown in Figure 5.22 as it leaves the basin. The flatter the curve, the greater the short-circuiting.

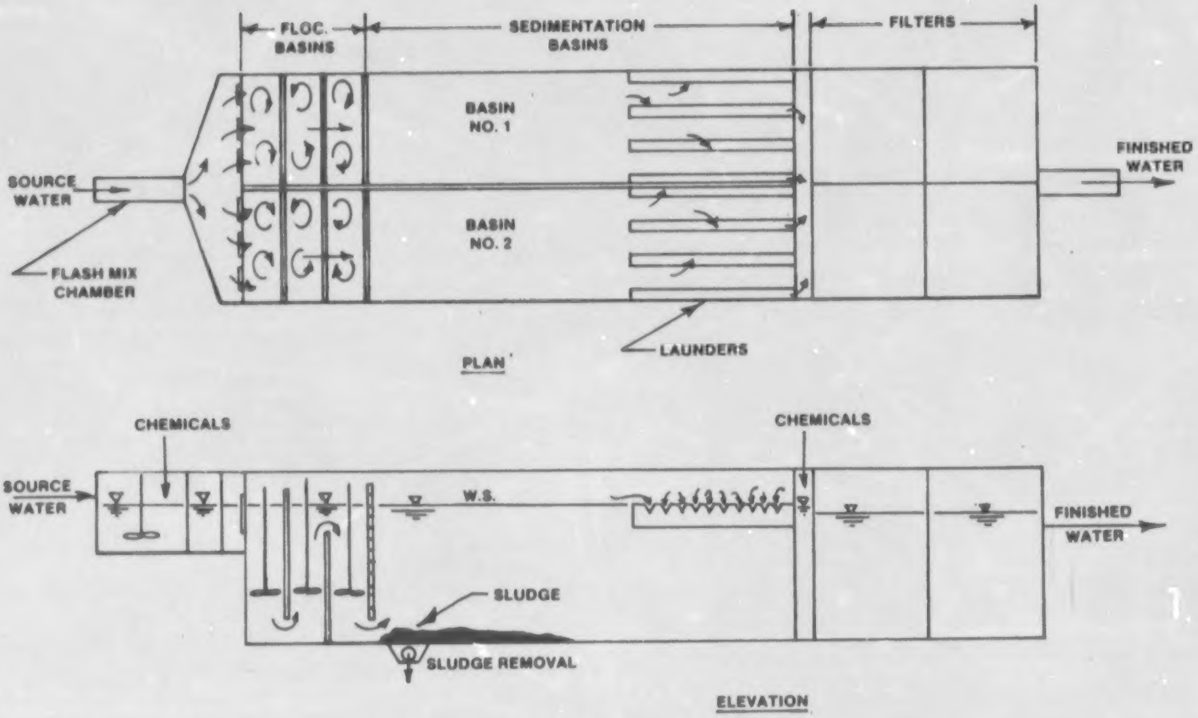

FLOC. BASINS
SEDIMENTATION BASINS
FILTERS
BASIN NO. 1
BASIN NO. 2
SOURCE WATER
FINISHED WATER
FLASH MIX CHAMBER
LAUNDERS
PLAN
CHEMICALS
CHEMICALS
SOURCE WATER
W.S.
FINISHED WATER
SLUDGE
SLUDGE REMOVAL
ELEVATION

Fig. 5.21 Rectangular sedimentation basin

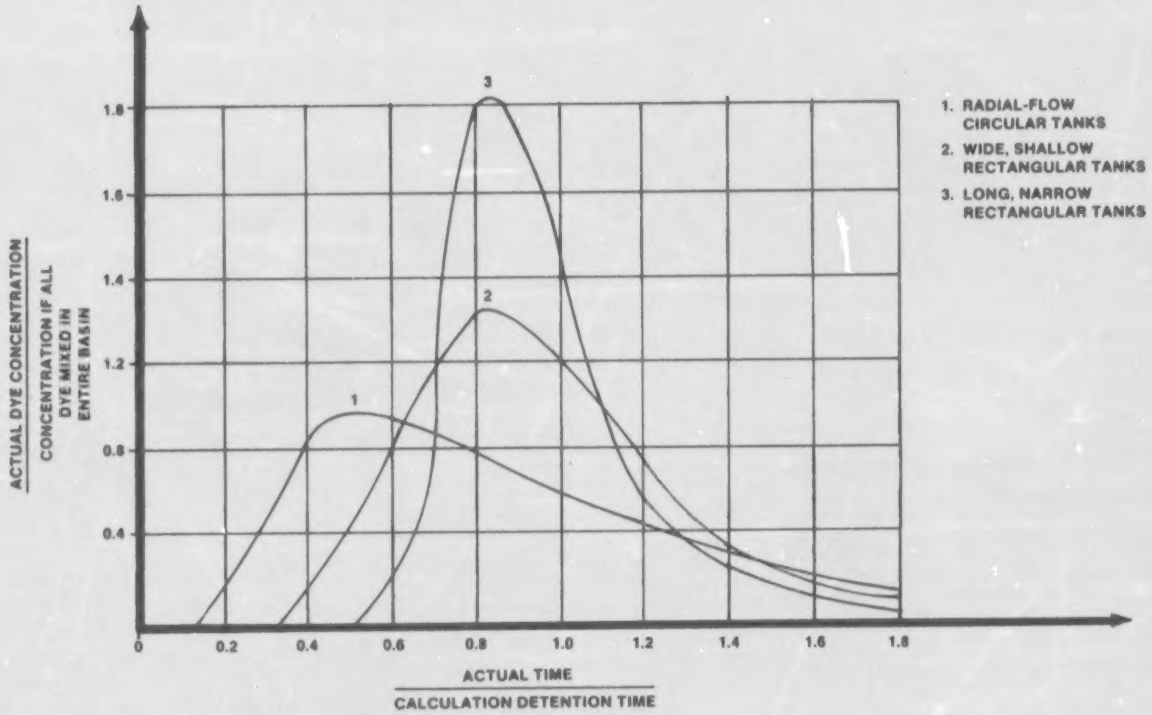


Fig. 5.22 Flow through times for various types of sedimentation basins

(Adapted from "Studies of Sedimentation Basin Design" by T.R. Camp, *SEWAGE AND INDUSTRIAL WASTES*, January 1953.)

FORMULAS

In order to calculate the detention time of a sedimentation basin, the volume of the basin and the flow must be known. The volume of a basin can be calculated from the dimensions of a basin. The dimensions of a basin can be obtained from the plan drawings for the treatment plant. These drawings will have the length, width and depth for rectangular sedimentation basins and the diameter and depth of circular clarifiers. The flow can be obtained from a flow meter or flow records.

To calculate the detention time, divide the flow in gallons per day into the tank volume in gallons. To convert this detention time in days to hours, multiply by 24 hours per day.

For rectangular basins,

$$\text{Basin Volume, gal} = (\text{L, ft})(\text{W, ft})(\text{Depth, ft})(7.48\ \text{gal/cu ft}).$$

For circular basins,

$$\text{Basin Volume, gal} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft}).$$

To calculate the theoretical detention time,

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

If the size of the basin and design detention time for the sedimentation basin are known, the maximum flow for the basin can be calculated by rearranging the detention time formula,

$$\text{Flow, gal/day} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Detention Time, hr}}$$

EXAMPLE 1

A water treatment plant treats a flow of 1.5 MGD. An examination of treatment plant design drawings reveals that the rectangular sedimentation basin is 75-feet long, 25-feet wide and has an effective (water) depth of 12 feet. Calculate the theoretical detention time in hours for the rectangular sedimentation basin.

Known	**Unknown**
Flow, MGD = 1.5 MGD	Detention Time, hr
Length, ft = 75 ft	
Width, ft = 25 ft	
Depth, ft = 12 ft	

1. Calculate the basin volume in gallons.

$$\begin{aligned}\text{Basin Volume, gal} &= (\text{L, ft})(\text{W, ft})(\text{D, ft})(7.48\ \text{gal/cu ft})\\ &= (75\ \text{ft})(25\ \text{ft})(12\ \text{ft})(7.48\ \text{gal/cu ft})\\ &= 168{,}300\ \text{gallons}\end{aligned}$$

2. Determine the theoretical detention time in hours.

$$\begin{aligned}\text{Detention Time, hr} &= \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}\\ &= \frac{(168{,}300\ \text{gal})(24\ \text{hr/day})}{1{,}500{,}000\ \text{gal/day}}\\ &= 2.7\ \text{hr}\end{aligned}$$

EXAMPLE 2

What is the maximum flow in MGD for the rectangular sedimentation basin in *EXAMPLE 1* if the theoretical detention time is 2 hours?

Known	**Unknown**
Length, ft = 75 ft	Maximum Flow, MGD
Width, ft = 25 ft	
Depth, ft = 12 ft	
Volume, gal (from *EXAMPLE 1*) = 168,300 gal	
Detention Time, hr = 2.0 hr	

1. Calculate the maximum flow in MGD.

$$\begin{aligned}\text{Flow, gal/day} &= \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Detention Time, hr}}\\ &= \frac{(168{,}300\ \text{gal})(24\ \text{hr/day})}{2.0\ \text{hr}}\\ &= 2{,}019{,}600\ \text{gal/day}\\ \text{Flow, MGD} &= 2.0\ \text{MGD}\end{aligned}$$

EXAMPLE 3

A water treatment plant has a circular clarifier for a sedimentation basin. The treatment plant design drawings indicate that the clarifier has a diameter of 60 feet and an average water depth of 12 feet. What is the theoretical detention time in hours for the basin when the flow is 2 MGD?

Known	**Unknown**
Diameter, ft = 60 ft	Detention Time, hr
Depth, ft = 12 ft	
Flow, MGD = 2 MGD	

1. Calculate the basin volume in gallons.

$$\begin{aligned}\text{Basin Volume, gal} &= (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})\\ &= (0.785)(60\ \text{ft})^2(12\ \text{ft})(7.48\ \text{gal/cu ft})\\ &= 253{,}662\ \text{gal}\end{aligned}$$

2. Determine the theoretical detention time in hours.

$$\begin{aligned}\text{Detention Time, hr} &= \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}\\ &= \frac{(253{,}662\ \text{gal})(24\ \text{hr/day})}{2{,}000{,}000\ \text{gal/day}}\\ &= 3.0\ \text{hrs}\end{aligned}$$

In this section we have calculated the detention time for a sedimentation basin. From a practical standpoint, however, you can anticipate problems by comparing the actual flow through your water treatment plant with the design flow. Whenever actual flows approach or exceed design flows, problems are likely to develop.

ONE CAUSE OF THE PROBLEM IS EXCESSIVE FLOWS.

You don't have to go through any calculations to know that your plant is hydraulically (flow) overloaded.

Also, when water temperature decreases, be prepared to reduce flows if problems should develop. The colder the water, the longer it takes particles to settle out. By reducing flows you are, of course, increasing the available detention time.

If the demand for water does not allow you to reduce flows, run jar tests with shorter detention times. Adjust the chemical doses as necessary to compensate for the colder water. There is very little an operator can do to control the sedimentation process. Adjusting chemicals and chemical feed rates is the major means by which operators can control water treatment processes.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 189.

5.2H How would you calculate the detention time for a sedimentation basin?

5.2I A rectangular sedimentation basin 50-feet long, 20-feet wide and 10-feet deep treats a flow of 0.8 MGD. What is the theoretical detention time?

5.24 Solids-Contact Clarification

by J.T. Monscvitz

5.240 Process Description

Solids-contact clarifiers (Figures 5.23 and 5.24) go by several names, which may be used interchangeably: solids-contact clarifiers, up-flow clarifiers, reactivators, and precipitators. The basic principles of operation are all the same, even though various manufacturers use different terms to describe how the mechanism may work.

The solids-contact units first got their start in the Midwest as a means of handling water softening problems which generated large amounts of sludge. Some manufacturers wished to call the sludge a slurry, but to most all water plant operators the settled material from coagulation or softening is simply called sludge.

From the early beginnings of the softening process, it soon became obvious that the solids-contact units could be used to remove turbidity from drinking water. A great number of up-flow clarifiers have found their way into water treatment plants as a means for turbidity removal in a very compact, single unit process. However, the internal mechanism consists of three distinct unit processes that function identically to any conventional coagulation-flocculation-sedimentation process chain.

A spearheading factor in the use of the solids contact, and no doubt how it derived its name, is based on a simple principle operators have used for many years very successfully. This principle is the re-cycling of settled slurry or sludge into coagulation and flocculation processes and taking advantage of mass action. Many years ago, some operators found that returning a portion of the previously settled sludge provided an excellent coagulation aid to the flocculation process.

In any event, if you will consider that the solids contact unit is basically coagulation and flocculation based upon the principle of re-cycling sludge, you will have a basic understanding of the solids-contact reactors, and perhaps "reactors" are a better description of the solids-contact units.

In the normal use of the solids-contact units for removal of turbidity, there are several outstanding advantages. Conversely, there are some disadvantages, but in the overall scheme the advantages may outweigh the disadvantages. You simply have one reaction unit to contend with, which can greatly reduce capital and maintenance costs because of the absence of independent chambers for flash mixing-coagulation-flocculation and sedimentation. The disadvantage is that you must be more competent, have an understanding of these processes, and be able to conceptually visualize all of these processes occurring in a small chamber or clarifier at the same time. Herein lies the problem confronting water plant operators when first faced with the operation of the up-flow clarifier. Operators often have trouble visualizing that all of these processes are occurring at the same time. Operators can become discouraged, blame the problem on the engineer who designed the plant, and wonder why a process that was meant to be simple becomes so complex to handle on a daily basis.

Often the initial judgment for the placing of a solids-contact unit into a treatment plant has its own limitations. Understanding the process will greatly enhance the operator's ability to cope with these problems. Also, understanding the process will not cause the operator to become upset because certain problems associated with the solids-contact units can and do occur.

A tremendous advantage in the use of the solids-contact units is the ability to accumulate slurry (sludge blanket), which can be taken advantage of during periods of severe taste and odor problems. By proper control of the slurry, you can develop a large amount of activated carbon in the slurry and take advantage of its *ABSORPTIVE*[7] characteristics. Similarly, when coagulation fails because of increased algal activities, you can take advantage of the slurry accumulation to carry the plant through the severe periods of the day when the chemicals will fail to react properly because of changes in the pH, alkalinity, carbonate, and dissolved oxygen. In the conventional plant, the operator cannot respond to this type of breakdown in the coagulation process as well as the operator can with a solids-contact unit. Once you decide that the algal activities are causing the problem (readily checked by pH and DO) you can — during the good periods of the day — increase the amount of slurry available and remove it during periods when the coagulation process is not functioning well. In doing so skillfully, you can well maintain a quality effluent from the solids-contact unit.

The point most often criticized concerning solids-contact units is their instability during rapid changes. Three factors must be considered.

1. Flow (through-put) rate and its rate of change,
2. Severe fluctuations in the turbidity level, and
3. Rapid changes in temperature.

Treating each of the above independently, the solids-contact unit is most unstable during rapid changes in the flow rate. The operator should identify and keep in mind the

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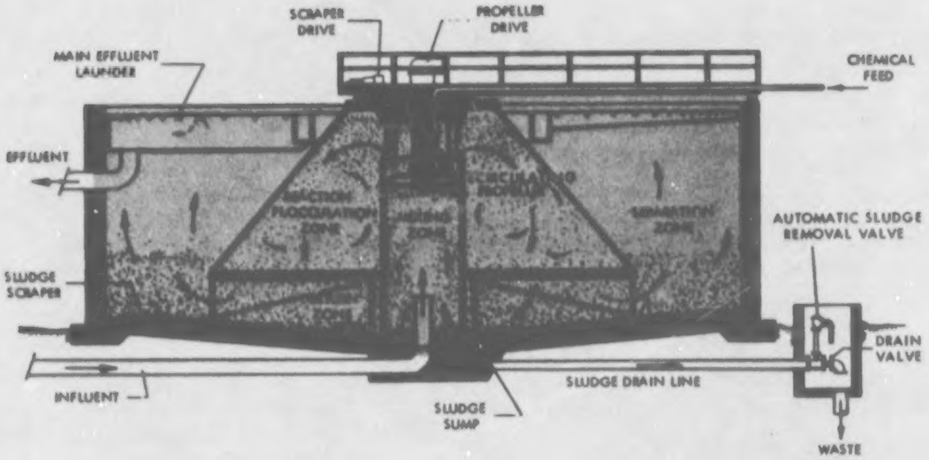
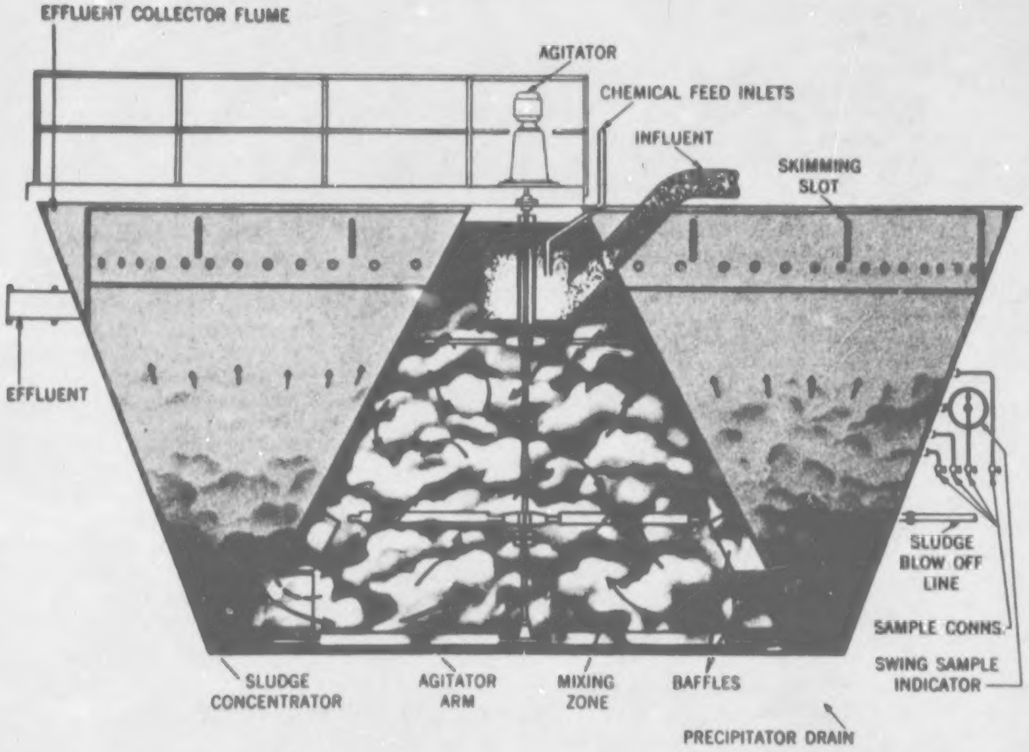
[7] *Absorption (ab-SORP-shun). Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).*

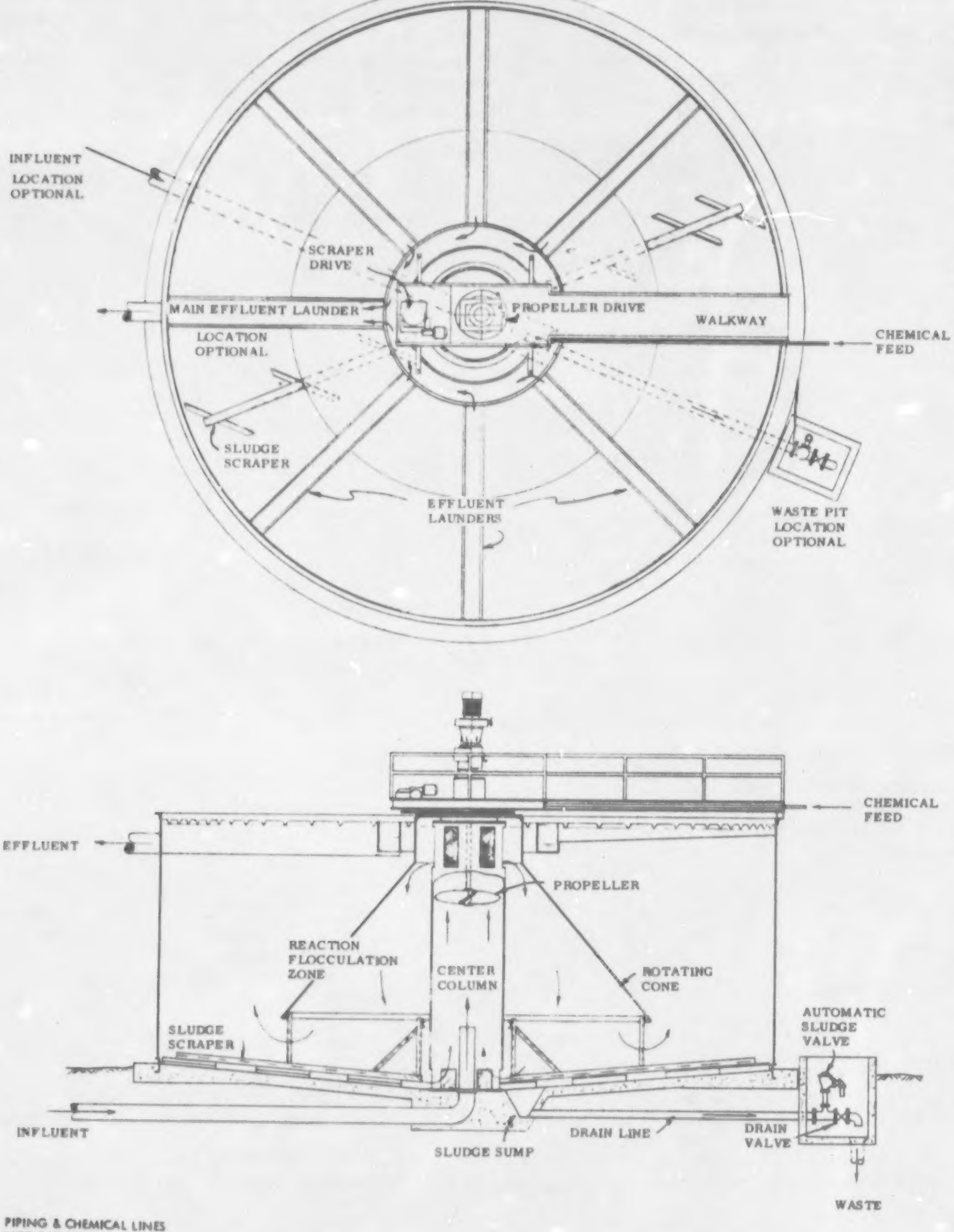

SCRAPER DRIVE
PROPELLER DRIVE
MAIN EFFLUENT LAUNDER
CHEMICAL FEED
EFFLUENT
REACTION FLOCCULATION ZONE
MIXING ZONE
RECIRCULATING PROPELLER
SEPARATION ZONE
AUTOMATIC SLUDGE REMOVAL VALVE
SLUDGE SCRAPER
DRAIN VALVE
SLUDGE DRAIN LINE
INFLUENT
SLUDGE SUMP
WASTE

Permission of General Filter


EFFLUENT COLLECTOR FLUME
AGITATOR
CHEMICAL FEED INLETS
INFLUENT
SKIMMING SLOT
EFFLUENT
SLUDGE BLOW OFF LINE
SAMPLE CONNS.
SWING SAMPLE INDICATOR
SLUDGE CONCENTRATOR
AGITATOR ARM
MIXING ZONE
BAFFLES
PRECIPITATOR DRAIN

Permission of Permutit Company

Fig. 5.23 Solids-contact clarifiers


INFLUENT
LOCATION
OPTIONAL
SCRAPER
DRIVE
MAIN EFFLUENT LAUNDER
PROPELLER DRIVE
WALKWAY
CHEMICAL
FEED
LOCATION
OPTIONAL
SLUDGE
SCRAPER
EFFLUENT
LAUNDERS
WASTE PIT
LOCATION
OPTIONAL
CHEMICAL
FEED
EFFLUENT
PROPELLER
REACTION
FLOCCULATION
ZONE
CENTER
COLUMN
ROTATING
CONE
AUTOMATIC
SLUDGE
VALVE
SLUDGE
SCRAPER
INFLUENT
SLUDGE SUMP
DRAIN LINE
DRAIN
VALVE
WASTE

PIPING & CHEMICAL LINES
NOT INCLUDED

Fig. 5.24 Plan and section views of a solids-contact clarifier
(Permission of General Filter)

design flow for which the unit was constructed. The design flow may be converted to an *OVERFLOW RATE*[8] which may be expressed as the rise rate (inches per minute or feet per minute). For each rise rate there will be an optimum (best) slurry to be maintained within the unit. A change in rising rate will increase the depth of the slurry without increasing its volume or density. Conversely, a decrease in flow rate will reduce the level of slurry without changing its volume.

Simple tests of changing flow rates can be performed to observe this phenomenon and clearly show the operator errors and/or predict the problem during changes. The level of slurries can be identified by sampling taps which are placed at various depths of the wall of the solids-contact reactor. The sampling taps should penetrate the wall and extend into the slurry zone. Frequently to accomplish this, you may have to make additions to the sampling pipes which were initially installed with the unit. However, by measuring and observing these depths, you can rapidly determine the rise or fall of the slurry and may have to adjust the recirculation device to accommodate these changes and/or place a more rigorous control on the rate of change of the flow. This, of course, is easy in a gravity flow system, when the water demands are moderate, and the change in flow can be performed slowly. However, in pressure systems, responding to rapid changes in demands or placing pumps into service at full capacity can easily upset an up-flow clarifier immediately. By observing the sampling taps, you can witness the crisis occurring and be next to helpless to respond. You will see the slurry rapidly rising in the settling zone, approach the overflow weirs, and spill onto the filters with a complete and total breakdown of the plant process.

The next factor which can upset solids-contact clarifiers is severe turbidity changes. This phenomena is not peculiar to flow rates, but is extremely troublesome when it occurs. The answer to the turbidity change is one of alertness on behalf of the operator. You must accurately forecast when the turbidity may arrive at the reaction zone and be prepared to cope with the turbidity change with the proper chemical dosage. You should attempt to forecast turbidity increases and increase the chemical dosage used prior to the arrival of turbidity and therefore have the unit in a mode in which the turbidity can be handled successfully. More will be discussed later concerning control of slurry and its influence on this process.

A very significant item is that of temperature. Changes in temperature will cause changes in density of water, which influences the particle settling rate. Conversely, simple heating by the sun on the wall of the tank or on the flocculant particles within the container will cause a certain amount of carryover to occur. Anyone being first initiated to a solids-contact unit may tend to become upset and over-react because of the potential carryover problem. This phenomenon is not one of real concern because as the position of the sun changes, the convection currents change and where a cloud of flocculant particles appear they soon will disappear and occur somewhere else. There is no real need to control this phenomenon if the overall settled turbidity meets your objective. So long as the major portion of the sludge blanket lies in the settling zone, the few clouds of flocculant particles (billowing-like clouds) really do not significantly harm the operation of the unit or the quality of the water produced. However, in an extremely cold water, you must consider increasing the chemical dosages by the use of polymers, activated silica, powdered calcium carbonate, or some other weighting agents that aid sedimentation and not coagulation.

Changing temperature and flow rates may make it impossible to control process upsets. The slurry rises to the weirs and is carried over onto the filters. When this happens you must reduce the flow rate. If possible, weighting agents should be used before changing flow rates in cold water. The use of weighting agents may cause problems with the slurry resulting in changes in recirculation rates. However, too high a recirculation rate may also cause the slurry to overflow onto the filters. During a change in temperature (cold water) you must be careful in changing the flow rate.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 189.

5.2J List two advantages of solids-contact units.

5.2K How can the level of the slurry or sludge blanket be determined in solids-contact units?

5.2L What should be done when a rapid change in turbidity is expected?

5.241 Fundamentals of Operation

There are three fundamental principles that you must be aware of in order to make a solids-contact unit function properly. These are:

1. Chemical dosage,
2. Recirculation, and
3. Sludge control.

All three of these principles are interrelated and frequently you may have trouble distinguishing which one may be the root of a problem you are encountering. However, if you will use the following analytical techniques, you should be able to separate the three fundamentals into separate groups and diagnose the cause of the upset. This is not to say that if you have one problem, it may not co-exist with the other two.

First, let's consider chemical dosage. As in conventional treatment plants, proper consideration must be given to chemical dosage, otherwise the entire system of solids-contact clarification will collapse. Therefore, you must be aware that there must be sufficient alkalinity in the raw water to react with the coagulant. Assuming for practical purposes the coagulant used is aluminum sulfate, for every mg/*L* of alum added, it will require 0.45 mg/*L* of bicarbonate alkalinity. To drive the chemical reaction sufficiently to the right

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[8] *Overflow Rate. One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called* SURFACE LOADING.

$$\text{Overflow Rate, GPD/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

If we divide the overflow rate by 7.48 gallons per cubic foot and also divide by 1440 minutes per day, we will have converted the overflow rate to a rise rate in feet per minute.

(that is to say, for precipitation to occur), there should be an excess of 20 mg/*L* of alkalinity present. You may have to add sodium hydroxide (caustic soda), calcium hydroxide (lime), or sodium carbonate (soda ash) to cause sufficient alkalinity to be present. For example, if there was only 20 mg/*L* of natural alkalinity present, for every mg/*L* of alum added, you should add 0.35 mg/*L* of lime if calcium hydroxide was being used.

All of this information can be verified by jar testing, which is fundamental in determining proper coagulation by chemical dosing. You should never attempt to make changes in solids-contact unit operation without first determining the proper chemical dosage through jar testing. For most solids-contact units, the chemical dosages that produce floc which gives the lowest turbidity within a five-minute settling period after stopping the jar tester, should be selected as the unit's dosage. Using the above criteria, the operator now can set the chemical feeders to dose the raw water entering the solids-contact unit.

The next principle is one of recirculation. Here most often the plant operator is misled by intuitive judgment. Recirculation is established by the speed of the impeller, turbine, pumping unit, or by air injection. Anyone of the above recirculation devices causes the slurry to recirculate through the coagulation (reaction) zone passing into the settling zone with a portion of the slurry being returned to the coagulation zone. If you can visualize a brown paper bag grasped in your hand, blown up with air, and sqeezed slightly from the bottom to expand that portion of the bag, this should give you a picture as to how the slurry should appear in the contact unit. In principle, you are attempting to chemically dose the raw water when it enters the reaction zone and is mixed with the recirculated sludge — coagulation and flocculation occurring in the reaction zone after which the water along with sludge passes into the settling zone.

At this point in the reaction, approximately one liter of water should rise and one liter as slurry should return into the reaction zone. In order to sort the principles out, you should keep a log of the speed (RPM) of the recirculation device. If air is used for mixing, then the cubic feet of air applied per minute should be recorded. A point to remember is that there is a direct relationship between the percentage of slurry present and the speed at which the mixing device is travelling. Also, there are conditions within the reactor that the operator must observe.

The first step here is to determine the percentage of slurry present in the reaction zone. This can be performed by what might be called a volume over volume (V/V) test. The test procedure used is to take a 100 m*L* graduated cylinder, select a sample from the reaction zone, let it sit for five minutes and determine the volume of slurry accumulated ([illegible]). At the same time you should observe the clarity of the supernatant (settled water) that remains in the graduated cylinder. The clarity of the water above the slurry (the supernatant) will indicate to you how well the chemical reaction is proceeding. The percentage of accumulated solids will indicate whether a proper amount of slurry is in the reaction zone. Customarily such reactors require 5 to 20 percent solids, or a higher percentage in the graduated cylinder at the end of a five to ten-minute settling period.

Through recordkeeping and experience, you will find an optimum percentage of solids to maintain. You should perform the above analyses hourly and more frequently when the raw water quality is undergoing change. Accurate records must be kept.

The final step in control of the solids-contact unit is the removal of sludge which has accumulated on the bottom of the clarifier (settling zone). There are several means of sludge collection; some methods are located in areas of clarifiers that hold the sludge and are controlled by opening and closing recirculation gates. Others have scrapers that collect the sludge and move it to a discharge sump. In both cases the sludge is removed by hydraulic means (water pressure) through a control valve. The sludge removal mechanisms are generally on a timer, which operates periodically for a time duration set by the operator. The means of making this judgment is quite simple. Once again, through the use of a graduated cylinder, a sample is taken from the sludge discharge line. The sludge being discharged should be 90 to 98 percent solids in a V/V test, as indicated above. A five to ten minute period should be sufficient to make this determination. Slurries or sludge weaker than 90 percent means that the operator is discharging a considerable amount of water and not leaving enough sludge to be recirculated into the reaction zone. If the percentage is considerably greater, then there may be too much sludge accumulated and the recirculation device may be becoming overloaded with too much return slurry.

If you will visualize the above reactions, you can see that with increased speed of the recirculation device, a larger amount of slurry can be retained in the unit. At the same time if this amount becomes too great, it may cause the sludge to rise and ultimately spill over the effluent weirs with the treated water. If the recirculation rate is too low, the solids may settle too soon and without sufficient recirculation will not return to the reaction zone. The absence of solids in the reaction zone causes improper coagulation. The net result is a failure of the total solids-contact system.

Considering the above principles and provided with some experience, you should be able to determine an optimum amount of slurry to be present that will satisfy a given recirculation rate, coupled with proper chemical dosage, and a sufficient percentage of solids for recycling. You should always be aware of the amount of solids in the reaction zone and, based upon practical experience, know approximately the percentage required. Some of the obvious difficulties in this judgment will occur as the raw water turbidity changes. For instance, in muddy streams carrying silt, sedimentation may occur very rapidly, thus requiring increased circulation rates to maintain sufficient slurry in the reaction zone even with proper chemical dosage, and also will require greater sludge removal rates. As the raw water turbidity becomes lighter, the increased circulation rate may cause the slurry blanket to rise to an uncontrolled depth in the settling zone, as will removing too much sludge. All of these problems are readily observed in the V/V test for solids determination in the reaction zone; also, this is cause for increased observations of the V/V during water quality changes.

Another problem may be caused by cold water when the recirculation rate may be too high for the densities of the particles present, suggesting that a set of recirculation speeds for warm-weather operation may be entirely different from those used during cold weather. As a remedy, the operator may select a nonionic polymer as a weighting agent to increase the settling rate in cold waters. Other alternative chemicals are powdered calcium carbonate or the use of activated silica. A note of caution in chemical dosage determination, is that the reactions in the jar tester should be reasonably rapid to assure comparable reactions within the solids-contact unit.

Another important point when determining chemical dosage for a solids-contact unit is that a specific set of jar test guidelines will be needed. For example, you should determine the volume of the reaction zone and the period of detention of the raw water in that reaction zone. This, along with knowledge of the speed of the recirculation device, should allow you to determine the detention time and flocculator speed in the jar tester.

In the real world, this means if the flow rate of the solids-contact unit is ten minutes in the reaction zone and the speed is two feet per second (0.6 m/sec), then the jar tester mixer should turn at a speed equal to two feet per second with a coagulation period of ten minutes. You should duplicate in the jar tester, as nearly as possible, those conditions of chemical dosage, detention period, and mixing speeds that occur in the solids-contact unit. Using these guidelines, you should be able to approach approximate real-world conditions in the laboratory and better optimize chemical dosages.

5.242 Maintenance

Solids-contact units, like all waterworks equipment, require at least a minimum of maintenance. The primary consideration is the recirculating device which needs regular inspection concerning the belt drive, gear boxes, and lubrication. Also if the unit has a sludge collector, then its drive and gear boxes require the same attention. The units should be inspected daily and lubricated in accordance with manufacturer's recommendations. A similar statement is applicable to the sludge collecting devices. Also, periodically the contact unit may need to be drained and the sludge collectors inspected for wear and corrosion.

Sludge collector devices are usually constructed of steel within a concrete container. Thus, there is a need to inspect the *CATHODIC PROTECTION*[9] system if one is provided with the unit. Weekly readings should be kept concerning the amperes and voltage supply. Changes in these readings should call for inspection of the devices and corrections made once the defects have been identified.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 189.

5.2M How is the proper chemical dose selected when operating a solids-contact unit?

5.2N List the devices that may be used to provide recirculation in a solids-contact unit.

5.2O How is the percentage of slurry present in the reaction zone determined?

5.243 Arithmetic for Solids-Contact Clarification

To successfully operate a solids-contact clarification unit requires very little arithmetic. The volume over volume test provides you with an indication of the settleability of the slurry or sludge in the sludge blanket. The detention time in the reaction zone is important to insure that there is sufficient mixing time and time for the chemical reactions (coagulation) to take place.

If the raw water is low in alkalinity and alum is the coagulant, lime may have to be added to provide enough alkalinity. With the necessary information and by following the step-by-step procedures outlined in this section, the setting on the lime feeder can be easily calculated.

FORMULAS

The volume over volume (V/V) test requires the collection of 100 m*L* slurry from a solids-contact unit in a 100 m*L* graduated cylinder. The slurry is allowed to sit for ten minutes and the volume of the settled slurry on the bottom of the graduated cylinder is measured and recorded.

$$\text{V/V, \%} = \frac{(\text{Settled Slurry, m}L)\,(100\%)}{\text{Total Volume, m}L}$$

The detention time in the reaction zone of a solids contact unit is calculated the same way the detention time in any basin is calculated. The flow is divided into the volume of the reaction zone. Any necessary adjustments are made for units, such as multiplying by 60 minutes per hour to convert a detention time from hours to minutes.

$$\begin{array}{c}\text{Detention}\\ \text{Time, min}\end{array} = \frac{(\text{Reaction Zone Volume, gal})\,(24\text{ hr/day})\,(60\text{ min/hr})}{\text{Flow, gal/day}}$$

To determine the lime dose that must be added to a raw water being treated, we need to know (1) the alkalinity of the raw water, (2) the alkalinity that must be present to assure complete precipitation of the alum, and (3) the amount of alkalinity that reacts with the alum.

1. Raw Water Alkalintiy, mg/*L* as HCO_3^-
2. Alkalinity Present for Precipitation, mg/*L* (at least 30 mg/*L*)
3. 0.45 mg/*L* Alkalinity (HCO_3^-) reacts with 1 mg/*L* Alum
4. 0.35 mg/*L* Lime ($Ca(OH)_2$) reacts with 1 mg/*L* Alum.

Procedure to calculate lime dose in mg/*L*.

1. Determine the alkalinity available to react with the alum.

$$\begin{array}{c}\text{Alkalinity Available,}\\ \text{mg}/L\end{array} = \begin{array}{c}\text{Raw Water}\\ \text{Alkalinity, mg}/L\end{array} - \begin{array}{c}\text{Alkalinity Present}\\ \text{for Precipitation, mg}/L\end{array}$$

2. Determine the amount of alum that will react with the available alkalinity.

$$\frac{0.45\text{ mg}/L\text{ Alkalinity}}{1.0\text{ mg}/L\text{ Alum}} = \frac{\text{Alkalinity Available, mg}/L}{\text{Alum Reacting, mg}/L}$$

or

$$\text{Alum Reacting, mg}/L = \frac{(1.0\text{ mg}/L\text{ Alum})(\text{Alkalinity Available, mg}/L)}{0.45\text{ mg}/L\text{ Alkalinity}}$$

3. Determine the milligrams per liter of alum that needs additional alkalinity (or is unreacted with). The total alum required is determined by the jar test.

$$\begin{array}{c}\text{Alum Needing}\\ \text{Alkalinity, mg}/L\end{array} = \text{Total Alum, mg}/L - \text{Alum Reacting, mg}/L$$

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[9] *Cathodic Protection (ca-THOD-ick). A system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic and concentrates corrosion on auxiliary anodic parts used for the purpose of corrosion instead of the structure.*

4. Determine the lime dose in milligrams per liter.

$$\frac{1\text{ mg}/L\text{ Alum}}{0.35\text{ mg}/L\text{ Lime}} = \frac{\text{Alum Needing Alkalinity, mg}/L}{\text{Lime Dosage, mg}/L}$$

or

$$\text{Lime Dosage, mg}/L = \frac{(0.35\text{ mg}/L\text{ Lime})(\text{Alum Needing Alkalinity, mg}/L)}{1\text{ mg}/L\text{ Alum}}$$

5. Determine the setting on the lime feeder in pounds per day.

$$\text{Lime Feed, lbs/day} = (\text{Flow, MGD})(\text{Lime Dose, mg}/L)(8.34\text{ lbs/gal})$$

6. Determine the setting on the lime feeder in grams per minute.

$$\text{Lime Feed, gm/min} = \frac{(\text{Flow, MGD})(\text{Lime Dose, mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(24\text{ hr/day})(60\text{ min/hr})(1000\text{ mg/gm})(1\text{ Million})}$$

We multiplied by 3.785 liters per gallon to cancel out the gallons in MGD and the liters in mg/*L*. By multiplying 1,000,000/1 Million we took care of the Million units. When we divided by 24 hr/day and 60 min/hr, we converted the feed rate from days to minutes. By dividing by 1000 mg/gm we changed the amount of lime to be fed from milligrams to grams so we could work with convenient numbers.

EXAMPLE 4

A graduated cylinder is filled to the 100 m*L* level with the slurry from a solids-contact unit. After ten minutes there is 21 m*L* of slurry on the bottom and 79 m*L* of clear water remaining in the top part of the cylinder. This is the volume over volume (V/V) test.

Known	Unknown
Settled Slurry, m*L* = 21 m*L*	V/V, %
Total Volume, m*L* = 100 m*L*	

Determine V/V as a percent

$$\text{V/V, \%} = \frac{(\text{Settled Slurry, m}L)(100\%)}{\text{Total Volume, m}L}$$

$$= \frac{(21\text{ m}L)(100\%)}{100\text{ m}L}$$

$$= 21\%$$

EXAMPLE 5

The reaction zone in a solids-contact clarifier is 11 feet in diameter and four-feet high. Find the detention time in minutes in the reaction zone if the flow is two MGD.

Known	Unknown
Diameter, ft = 11 ft	Detention Time, min
Height, ft = 4 ft	
Flow, MGD = 2 MGD	
= 2,000,000 GPD	

1. Calculate the volume of the reaction zone in gallons.

$$\text{Volume, gal} = (0.785)(\text{Diameter, ft})^2(\text{Height, ft})(7.48\text{ gal/cu ft})$$

$$= (0.785)(11\text{ ft})^2(4\text{ ft})(7.48\text{ gal/cu ft})$$

$$= 2842\text{ gal}$$

2. Calculate the detention time in the reaction zone in minutes.

$$\text{Detention Time, min} = \frac{(\text{Reaction Zone Volume, gal})(24\text{ hr/day})(60\text{ min/hr})}{\text{Flow, gal/day}}$$

$$= \frac{(2842\text{ gal})(24\text{ hr/day})(60\text{ min/hr})}{2{,}000{,}000\text{ gal/day}}$$

$$= 2.05\text{ min}$$

EXAMPLE 6

A raw water has an alkalinity of 36 mg/*L* as bicarbonate (HCO_3^-). A chemical dose of 52 mg/*L* of alum (from a jar test) is needed to reduce the turbidity from 75 TU down to 1.0 TU. At least 30 mg/*L* of alkalinity must be present to assure complete precipitation of the alum added. Find the dose of lime ($Ca(OH)_2$) in mg/*L* that will be needed to complete this reaction.

Known	Unknown
Raw Water Alkalinity, mg/*L* = 36 mg/*L*	Lime Dose, mg/*L*
Total Alum Required, mg/*L* = 52 mg/*L*	
Alkalinity Present for Precipitation, mg/*L* = 30 mg/*L*	

ALUM DOSE IN POUNDS PER HOUR

1. Determine the alkalinity available to react with the alum.

$$\text{Alkalinity Available mg}/L = \text{Raw Water Alkalinity, mg}/L - \text{Alkalinity Present for Precipitation, mg}/L$$

$$= 36\text{ mg}/L - 30\text{ mg}/L$$

$$= 6\text{ mg}/L$$

2. Determine the amount of alum that will react with the available alkalinity.

$$\text{Alum Reacting, mg}/L = \frac{(1.0\text{ mg}/L\text{ Alum})(\text{Alkalinity Available, mg}/L)}{0.45\text{ mg}/L\text{ Alkalinity}}$$

$$= \frac{(1.0\text{ mg}/L\text{ Alum})(6\text{ mg}/L\text{ Alkalinity})}{0.45\text{ mg}/L\text{ Alkalinity}}$$

$$= 13.3\text{ mg}/L\text{ Alum}$$

3. Determine the milligrams per liter of alum that needs additional alkalinity (or is not reacted with).

$$\text{Alum Needing Alkalinity, mg}/L = \text{Total Alum, mg}/L - \text{Alum Reacting, mg}/L$$

$$= 52\text{ mg}/L - 13.3\text{ mg}/L$$

$$= 38.7\text{ mg}/L$$

4. Determine the lime dose in milligrams per liter.

$$\text{Lime Dose, mg}/L = \frac{(0.35\ \text{mg}/L\ \text{Lime})\ (\text{Alum Needing Alkalinity, mg}/L)}{1\ \text{mg}/L\ \text{Alum}}$$

$$= \frac{(0.35\ \text{mg}/L\ \text{Lime})\ (38.7\ \text{mg}/L\ \text{Alum})}{1\ \text{mg}/L\ \text{Alum}}$$

$$= 13.5\ \text{mg}/L$$

NOTE: This dose may be verified by the use of a jar test by selecting an alum dose and trying different lime doses.

EXAMPLE 7

If the raw water in Example 6 needs a lime dose of 13.5 mg/*L*, what should be the setting on the line feeder in (1) pounds per day and (2) grams per minute when the flow is 2.0 MGD?

Known		**Unknown**
Lime Dose, mg/*L*	= 13.5 mg/*L*	1. Lime Feed, lbs/day
Flow, MGD	= 2.0 MGD	2. Lime Feed, gm/min

1. Determine the setting on the lime feeder in pounds per day.

$$\text{Lime Feed, lbs/day} = (\text{Flow, MGD})\ (\text{Lime Dose, mg}/L)\ (8.34\ \text{lbs/gal})$$

$$= (2.0\ \text{MGD})\ (13.5\ \text{mg}/L)\ (8.34\ \text{lbs/gal})$$

$$= 225\ \text{lbs lime/day}$$

2. Determine the setting on the lime feeder in grams per minute.

$$\text{Lime Feed, gm/min} = \frac{(\text{Flow, MGD})\ (\text{Lime Dose, mg}/L)\ (3.785\ L/\text{gal})\ (1{,}000{,}000)}{(24\ \text{hr/day})\ (60\ \text{min/hr})\ (1000\ \text{mg/gm})\ (1\ \text{Million})}$$

$$= \frac{(2.0\ \text{MGD})\ (13.5\ \text{mg}/L)\ (3.785\ L/\text{gal})\ (1{,}000{,}000)}{(24\ \text{hr/day})\ (60\ \text{min/hr})\ (1000\ \text{mg/gm})\ (1\ \text{Million})}$$

$$= 71\ \text{grams lime/minute}$$

5.25 Sludge Handling

5.250 Sludge Characteristics

Water treatment plant sludges are typically alum sludges, with solids concentrations varying from 0.25 to 10 percent when removed from the basin. In gravity flow sludge removal systems, the solids concentration should be limited to about 3 percent. If the sludge is to be pumped, solids concentrations as high as 10 percent can be readily transported.

In horizontal-flow sedimentation basins preceded by coagulation and flocculation, over 50 percent of the floc will settle out in the first third of the basin length. Operationally, this must be considered when establishing the frequency of operation of sludge removal equipment. Also you must consider the volume or amount of sludge to be removed and the sludge storage volume available in the basin.

5.251 Sludge Removal Systems

Sludge which accumulates on the bottom of sedimentation basins must be periodically removed for the following reasons:

1. To prevent interference with the settling process (such as resuspension of solids due to scouring);
2. To prevent the sludge from becoming *SEPTIC*[10] or providing an environment for the growth of microorganisms that can create taste and odor problems; and
3. To prevent excessive reduction in the cross-sectional area of the basin (reduction of detention time).

In large-scale plants, sludge is normally removed on an intermittent basis with the aid of mechanical sludge removal equipment. However, in smaller plants with low solids loading, manual sludge removal may prove to be the more cost-effective.

In manually cleaned basins, the sludge is allowed to accumulate until it reduces settled water quality. High levels of sludge reduce the detention time and floc carries over to the filters. The basin is then dewatered (drained), most of the sludge is removed by stationary or portable pumps, and the remaining sludge is removed with squeegies and hoses. Basin floors are usually sloped towards a drain to help sludge removal. The frequency of shutdown for cleaning will vary from several months to a year or more, depending on source water quality (amount of suspended matter in the water).

In larger plants, a variety of mechanical devices (Figure 5.25) can be used to remove sludge including:

1. Mechanical rakes (Figure 5.7),
2. Drag-chain and flights, and
3. Traveling bridges (Figure 5.8).

Circular or square basins are usually equipped with rotating sludge rakes. Basin floors are sloped towards the center, and the sludge rakes progressively push the sludge towards a center outlet.

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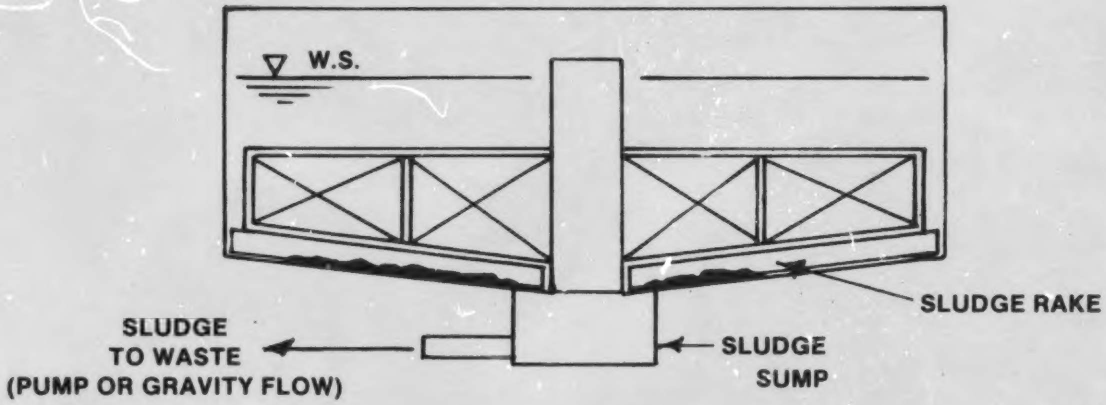
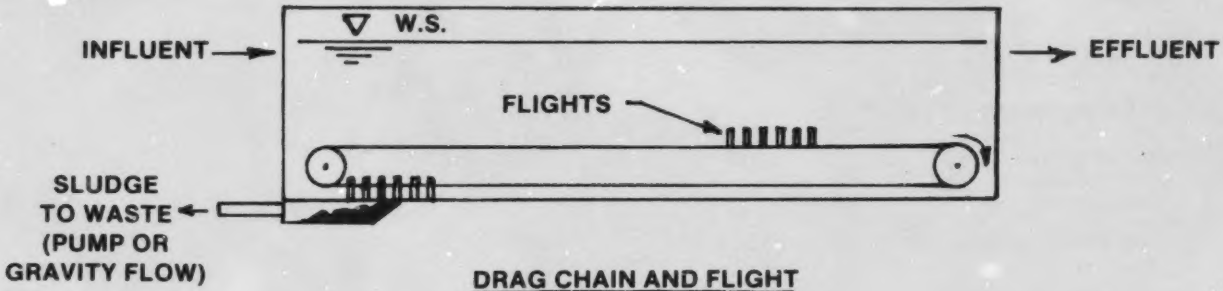
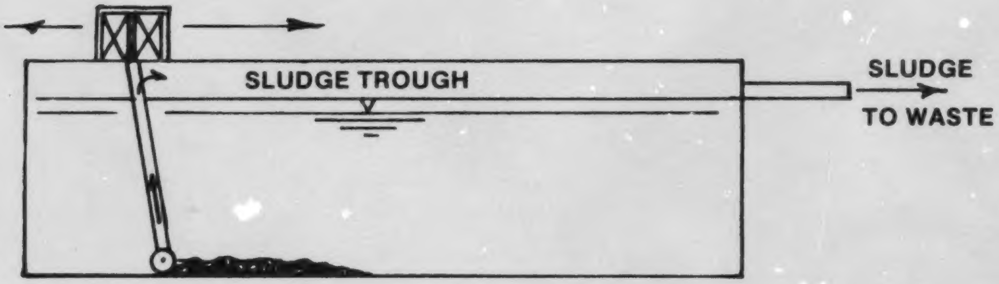
[10] *Septic (SEP-tick). A condition produced by bacteria when all oxygen supplies are depleted. If severe, bottom deposits and water turn black, give off foul odors, and the water has a greatly increased chlorine demand.*


W.S.
SLUDGE RAKE
SLUDGE TO WASTE (PUMP OR GRAVITY FLOW)
SLUDGE SUMP

MECHANICAL RAKES
(CIRCULAR OR SQUARE BASINS)


W.S.
INFLUENT
EFFLUENT
FLIGHTS
SLUDGE TO WASTE (PUMP OR GRAVITY FLOW)

DRAG CHAIN AND FLIGHT
(RECTANGULAR BASINS)


SLUDGE TROUGH
SLUDGE TO WASTE

TRAVELING BRIDGE — PUMP OR SIPHON
(RECTANGULAR BASINS)

Fig. 5.25 Mechanical sludge removal systems

In rectangular basins, the simplest sludge removal mechanism is the chain and flight system. An endless chain outfitted with wooden flights (scrapers) pushes the sludge into a sump. The disadvantage of this system and of the rotating rakes previously described is high operation and maintenance costs. Most of the moving (wearing) parts are submerged so the basin has to be dewatered to perform major maintenance.

In an attempt to reduce operation and maintenance costs (as well as capital equipment costs), and to improve sludge removal equipment maintainability, the traveling bridge was developed. This bridge looks like an old highway bridge except it has no deck for cars. The traveling bridge spans the width of the sedimentation basin and travels along the length of the basin walls. Movable sludge sweeps, which are hung from the bridge structure, remove the sludge from the basin floor with suction pumps or by siphon action. There are few submerged parts in this system and these can normally be removed for maintenance without dewatering the basin. Traveling bridge sludge removal systems will operate effectively on the simplest of basin designs.

Sludge may be discharged into sludge basins or ponds for liquid-solids separation. Ultimately the sludge may be disposed of in a landfill. See Chapter 10, "Plant Operations," and Chapter 17, "Handling and Disposal of Process Wastes," for additional details.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 189.

5.2P Alum sludge solids concentrations typically vary from ____ to ____ percent when removed from a sedimentation basin.

5.2Q What factors must be considered when determining how frequently you will need to operate sludge removal equipment?

5.2R Why must accumulated sludge be removed periodically from the bottom of sedimentation basins?

5.252 Operation of Sludge Removal Equipment

Accumulated sludge in the basin bottom or sludge sump is periodically removed for further processing (dewatering) and ultimate disposal. The frequency of sludge removal or transfer depends on the rate of sludge buildup and this is directly related to the amount of suspended material and floc removed in the sedimentation process. Other factors influencing the frequency of sludge removal include the size of the sludge sump and the capacity of the sludge pump. In alum coagulation operations this generally means that sludge removal equipment need only be operated once per shift or perhaps less frequently (daily). If polymers are used as the primary coagulant and the source water suspended solids concentration is low (less than 5 mg/*L*), sludge removal equipment need only be operated once or twice per week.

In some water treatment plants the operator measures the depth of the accumulated sludge deposit and uses this data to determine the operating frequency of the sludge removal equipment. This measurement can be made with a sludge blanket sounder, a bubbler tube, an aspirator, or an ultrasonic level indicator.

Perhaps the simplest sludge blanket measuring device is the "sludge blanket sounder." This device consists of a piece of one-quarter inch (6 mm) thick hardware cloth disc about 18-inches (450 mm) in diameter. The disc is suspended from a lightweight chain by a three-point suspension (see Figure 5.26).

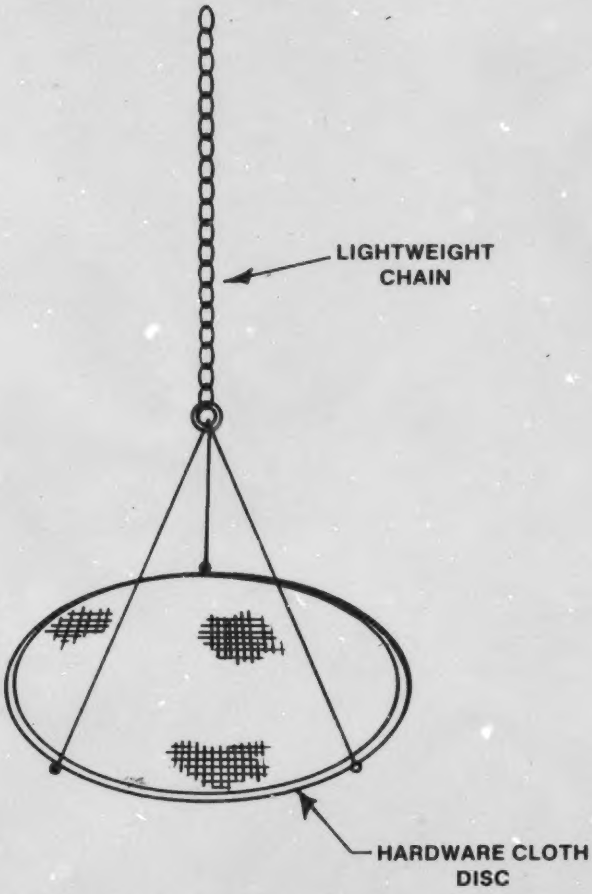


Fig. 5.26 Sludge blanket sounder

(Adapted from *MANUAL OF WASTEWATER OPERATIONS* prepared by the Texas Water Utilities Association)

In using this sounding device, the disc is slowly lowered into the sedimentation basin. When the disc reaches the top of the sludge blanket it stops its descent, and a depth reading is taken from markings on the chain.

After you have determined an appropriate time interval for sludge equipment operation, the sludge discharge should be periodically checked to determine the concentration of the sludge solids. This is generally done by observation. If the sludge is too thick and bulks, the frequency of sludge removal should be increased. Likewise, if the sludge concentration is too low in solids (soupy), decrease the frequency of sludge removal.

Some water treatment plants are furnished with semiautomatic sludge removal equipment which can be adjusted to change the frequency of sludge removal equipment operation by merely resetting a time clock.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 189 and 190.

5.2S How can the depth of sludge in a sedimentation basin be measured?

5.2T If the sludge being pumped from a sedimentation basin is too low in solids (soupy), what should the operator do?

5.3 INTERACTION WITH OTHER TREATMENT PROCESSES

The purposes of the sedimentation process are to remove suspended solids from the water being treated and to reduce the load on the filters. If adequate detention time and basin surface area are provided in the sedimentation basins, solids removal efficiencies greater than 95 percent can be achieved. However, high sedimentation basin removal efficiencies may not always be the most cost-effective way to remove suspended solids.

In low turbidity source waters (less than about 10 *TU*[11]), effective coagulation, flocculation, and filtration may produce a satisfactory filtered water without the need for sedimentation. In this case, the coagulation-flocculation process is operated to produce a highly filtrable *PIN-POINT FLOC*, which does not readily settle due to it's small size. Instead, the pin-point floc is removed by the filters.

However, there is a practical limitation in applying this concept to higher turbidity conditions. If the filters become overloaded with suspended solids, they will quickly clog and need frequent backwashing. This can limit plant production and cause a degradation in filtered water quality.

Thus, the sedimentation process should be operated from the standpoint of overall plant efficiency. If the source water turbidity is only 3 TU, and jar tests indicated that 0.5 mg/*L* of cationic polymer is the most effective coagulant dosage, then you cannot expect the sedimentation process to remove a significant fraction of the suspended solids. On the other hand, source water turbidities in excess of 50 TU will probably require a high alum dosage (or other primary coagulant) for efficient solids removal. In this case, the majority of the suspended particles and alum floc should be removed in the sedimentation basin.

5.4 PROCESS CONTROL

The actual performance of sedimentation basins depends on the settling characteristics of the suspended particles and the flow rate through the sedimentation basins. To control the settling characteristics of the suspended particles, adjust the chemical coagulant dose and the coagulation-flocculation process (see Chapter 4). The flow rate through the sedimentation basin controls the efficiency of the process in removing suspended particles. The higher the flow rate, the lower the efficiency (the fewer suspended particles are removed). Once the actual flow rate becomes greater than the design flow rate, you can expect an increase in suspended particles flowing over the V-notch weirs.

From a practical standpoint, you will want to operate sedimentation basins near design flows. However, to achieve the intended removal of suspended particles once design flows are exceeded, suspended particles leaving the sedimentation basin may overload the filters with solids and require additional filter backwashing. Study the settling characteristics of the particles by using laboratory jar tests. Then verify your test results and make adjustments based on actual performance of the water treatment plant.

During periods of low flows the use of all sedimentation basins may not be necessary. Since the cost to operate a basin is very low, we recommend that all basins be kept in service except during periods of draining for maintenance and repairs.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 190.

5.3A Under what circumstances are sedimentation basins needed to treat water?

5.4A The actual performance of sedimentation basins depends on what two major factors?

End of Lesson 1 of 2 Lessons
on
SEDIMENTATION

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[11] *Turbidity Units. Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.*

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. SEDIMENTATION

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. How would you adjust a sedimentation process to colder water temperatures?
2. Why are rectangular sedimentation basins commonly used to treat water?
3. Why should water treatment plants have at least two sedimentation basins?
4. What problems are created when the sludge buildup on the bottom of the sedimentation tank becomes too great?
5. What problems could develop if sludge is allowed to remain too long on the bottom of a sedimentation basin?
6. Sudden changes in what three factors can cause operating problems in solids-contact units?
7. What problems can develop in a solids-contact unit if the recirculation rate is too high or too low?
8. How often should sludge removal equipment be operated?

Chapter 5. SEDIMENTATION

(Lesson 2 of 2 Lessons)

5.5 OPERATING PROCEDURES ASSOCIATED WITH NORMAL PROCESS CONDITIONS

5.50 Indicators of Normal Operating Conditions

From a water quality standpoint, filter effluent turbidity is a good indication of overall process performance. However, you must still monitor the performance of each of the individual water treatment processes, including sedimentation, in order to anticipate quality or performance changes. Normal operating conditions are considered to be conditions within the operating ranges of your plant, while abnormal conditions are unusual or difficult to handle conditions. Changes in raw water quality may be considered a normal condition for many plants and an abnormal condition for other water treatment plants.

In the normal operation of the sedimentation process you will monitor (Figure 5.27):

1. Turbidity of the water entering and leaving the sedimentation basin, and
2. Temperature of the entering water.

Turbidity of the entering water indicates the floc or solids loading on the sedimentation process. Turbidity of the water

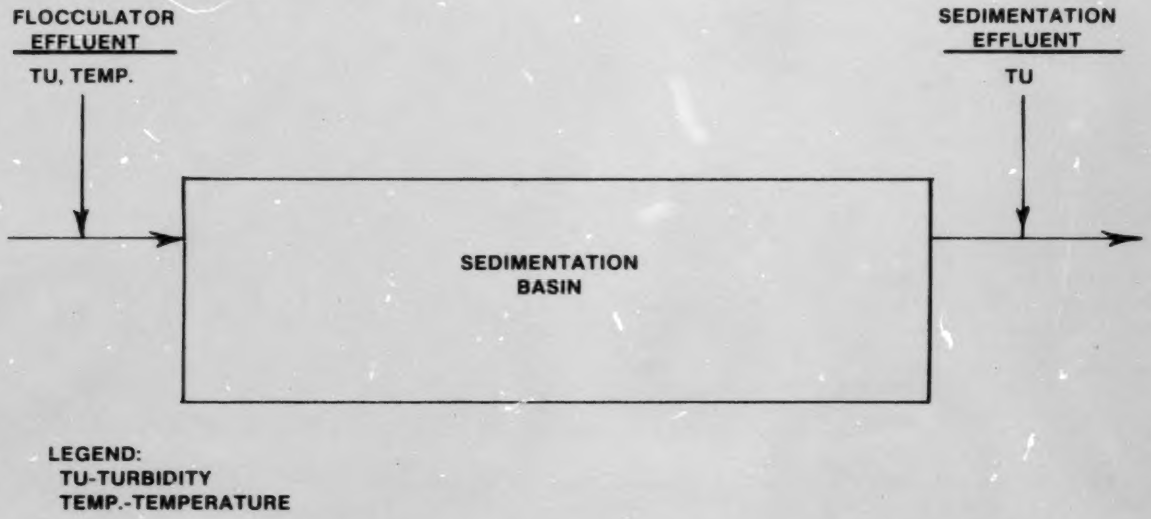

Fig. 5.27 Sedimentation process monitoring water quality indicator and sample points

leaving the basin reveals the effectiveness or efficiency of the sedimentation process. Low levels of turbidity are desirable to minimize the floc loading on the filters.

Temperature of the water entering the sedimentation basin is very important. Usually water temperature changes are gradual, depending on time of the year and the weather. As the water becomes colder, the particles will settle slower. To compensate for this change, you should perform jar tests (refer to Chapter 4) and adjust the coagulant dosage to produce a heavier and thus a faster settling floc. Another possibility is that if the demand for water decreases during colder weather, the flow to be treated can be reduced which will produce longer detention times. Longer detention times will allow slower settling particles or floc to be removed in the sedimentation basins.

Visual checks of the sedimentation process should include observation of floc settling characteristics, distribution of floc at the basin inlet, and clarity of settled water spilling over the launder weirs. An uneven distribution of floc, or poorly settling floc may indicate that a raw water quality change has occurred or that operational problems may have developed.

5.51 Process Actions

In rectangular and circular sedimentation basins, you can generally make a judgment about the performance of the sedimentation process by observing how far the floc are visible beyond the basin inlet. When sedimentation is working well, the floc will only be visible for a short distance. When sedimentation is poor, the floc will be visible for a long distance beyond the inlet.

In upflow or solids-contact clarifiers, the depth of the sludge blanket and the density of the blanket are useful monitoring tools. If the sludge blanket is of normal density (measured as milligrams of solids per liter of water) but is very close to the surface, more sludge should be wasted. If the blanket is of unusually light density, the coagulation-flocculation process (chemical dosage) must be adjusted to improve performance.

With any of the sedimentation processes, it is useful to observe the quality of the effluent as it passes over the launder weir. Flocs coming over at the ends of the basin are indicative of density currents, short-circuiting, sludge blankets that are too deep, or high flows. The clarity of the effluent is also an effective indicator of coagulation-flocculation efficiency.

Process equipment should be checked regularly to assure adequate performance. Proper operation of sludge removal equipment should be verified each time the equipment is operated, since sludge removal discharge piping systems are subject to clogging. Free flowing sludge can be readily observed if sight glasses are incorporated in the sludge discharge piping. Otherwise, the outlet of the sludge line should be observed during sludge pumping. Frequent clogging of the sludge discharge line is an indication that the sludge concentration is too high. If this occurs, you should increase the frequency of operation of the sludge removal equipment. This problem can be accurately diagnosed by performing a sludge solids volume analysis[12] in the laboratory, if this capability is available to the operator.

The operator should routinely inspect physical facilities and equipment as part of good housekeeping and maintenance practice. Abnormal equipment conditions should be corrected or reported to maintenance personnel, and basin water surfaces and launders should be kept free of leaves, twigs, and other debris which might jam or foul mechanical equipment such as valves and meters.

A summary of routine sedimentation process actions is given in Table 5.2. Actual frequency of monitoring should be based on source of water supply and variations in the supply.

5.52 Recordkeeping

Recordkeeping is one of the most important *ADMINISTRATIVE* functions of the water treatment plant operator. In the routine daily operation of the sedimentation process, you will maintain a daily operations log of process performance and water quality characteristics. Keep the following records:

1. Influent and effluent turbidity and influent temperature,
2. Process production inventory (amount of water processed and volume of sludge produced), and

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[12] *Collect a sludge sample and pour a known volume into a drying dish. Place the sample dish in a drying oven and evaporate the sample to dryness (usually about one hour) at 103 to 105°C. Weigh the remaining solids.*

$$\text{Sludge Solids, \%} = \frac{(\text{Weight of Sample, mg})(1\text{ mL})(100\%)}{(\text{Volume of Sample, mL})(1000\text{ mg})}$$

TABLE 5.2 SUMMARY OF ROUTINE SEDIMENTATION PROCESS ACTIONS

1. Monitor Process Performance and Evaluate Water Quality Conditions	**Location**	**Frequency[a]**	**Possible Operator Actions**
• Turbidity	Influent/Effluent	At lease once every 2 hours	1. Increase sampling frequency when process water quality is variable. 2. Perform jar tests if indicated (see procedure in Chapter 4, "Coagulation and Flocculation"). 3. Make necessary process changes. a. Change coagulant. b. Adjust coagulant dosage. c. Adjust flash mixer/flocculator mixing intensity. d. Change frequency of sludge removal. 4. Verify response at appropriate time.
• Temperature	Influent	Occasionally	
2. Make Visual Observations	**Location**	**Frequency[a]**	**Possible Operator Actions**
• Floc settling characteristics	First half of basin	At least once per 8-hour shift	1. Perform jar tests if indicated. 2. Make necessary process changes. a. Change coagulant. b. Change coagulant dosage. c. Adjust flash mixer/flocculator mixing intensity. d. Change frequency of sludge removal. 3. Verify response to process changes at appropriate time.
• Floc distribution	Inlet	At least once per 8-hour shift	
• Turbidity (clarity) of settled water	Launders or settled water conduit	At least once per 8-hour shift	
3. Check Process and Sludge Removal Equipment Condition	**Location**	**Frequency[a]**	**Possible Operator Actions**
• Noise	Various	Once per 8-hr shift	1. Correct minor problems. 2. Notify others of major problems.
• Vibration	Various	Once per 8-hr shift	
• Leakage	Various	Once per 8-hr shift	
• Overheating	Various	Once per 8-hr shift	
4. Operate Sludge Removal Equipment	**Location**	**Frequency[a]**	**Possible Operator Actions**
• Perform normal operations sequence	Sed. Basin	Depends on process conditions (may vary from once per day to several days or more)	1. Change frequency of operation. a. If sludge is too watery, decrease frequency of operation and/or pumping rate. b. If sludge is too dense, bulks, or clogs discharge lines, increase frequency of operation and/or pumping rate. c. If sludge is septic, increase frequency of operation and/or pumping rate.
• Observe conditions of sludge being removed	Sed. Basin	Depends on process conditions (may vary from once per day to several days or more)	
5. Inspect Facilities	**Location**	**Frequency[a]**	**Possible Operator Actions**
• Check sedimentation basins	Various	Once every 2 hours	1. Report abnormal conditions. 2. Make flow changes (see Chapter 10, "Plant Operation"), or adjust launder weirs. 3. Remove debris from basin water surface.
• Observe basin water levels and depth of water flowing over launder weirs	Various	Once per 8-hr shift	
• Observe basin water surface	Various	Once per 8-hr shift	
• Check for algae buildup on basin walls and launders	Various	Occasionally	

[a] Frequency of monitoring should be based on source of water supply and variations in the supply.

3. Process equipment performance (types of equipment in operation, maintenance procedures performed and equipment calibration).

Entries in logs should be neat and legible, should reflect the date and time of an event, and should be initialled by the operator making the entry.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 190.

5.5A What items should an operator monitor during the normal operation of the sedimentation process?

5.5B How often should visual observations and laboratory evaluation of sedimentation process performance be conducted?

5.5C How can an operator determine if sludge lines are free flowing?

5.5D What should be attempted if the sludge line plugs frequently?

5.5E In the routine operation of the sedimentation process, what types of records should be maintained?

5.6 OPERATING PROCEDURES ASSOCIATED WITH ABNORMAL PROCESS CONDITIONS

5.60 Indicators of Abnormal Conditions

Sudden changes in source or process water quality indicators such as turbidity, pH, alkalinity, temperature, chlorine demand (source water), and color are signals that you should immediately review the performance of the coagulation-flocculation process and also the sedimentation process.

5.61 Process Actions

Significant changes in source water turbidity levels, either increases or decreases, require that you verify the effectiveness of the sedimentation process in removing suspended solids and floc. Measurement of turbidity levels at the sedimentation basin inlet and outlet will give you a rough idea of process removal efficiency. Grab samples can be used for this determination. Visual observations of floc dispersion and settling characteristics will also help you evaluate process performance.

Increasing source water turbidity levels may be the result of rainfall and runoff into a river, stream or impoundment serving the treatment plant. If turbidity levels are increasing rapidly, verify the effectiveness of the coagulant chemicals and dosages being applied at the flash mixer. The efficiency of the coagulation-flocculation process directly affects the performance of the sedimentation process. Performance of jar tests (described in Chapter 4, "Coagulation and Flocculation") in the laboratory may be used to simulate process performance in the treatment plant. Use the test results to adjust chemical dosages in the flash mixer.

In the event that higher dosages of alum or other coagulants are required for effective removal of increased suspended solids loads, you may also need to increase the frequency of operation of sludge removal equipment. On the other hand, if source water turbidity levels decrease, less frequent operation of sludge removal equipment may be indicated.

Changes in source water alkalinity and pH caused by storms, waste discharges or spills have a significant impact on the performance of the sedimentation process as a result of decreased coagulation-flocculation process performance. Again, you need to perform jar tests to assess the impact of source water or process water quality changes.

Water temperature changes may also require a reevaluation of process performance. Decreasing water temperatures lower the rate at which particles settle, while higher water temperatures increase particle settling velocities. Thus, temperature changes may also require that jar tests be performed to establish optimum floc settling rates. Temperature changes are usually gradual over time so sudden changes in temperature are unlikely unless a source water change is made.

Sudden increases in settled water turbidity could spell trouble for the operator in the operation of the filtration process. Floc carryover from the sedimentation basin will cause premature clogging of filters and may result in the degradation of filtered water quality. Filtration process actions are discussed in Chapter 6, "Filtration."

Table 5.3 gives a summary of sedimentation process problems, how to identify the causes of problems and also how to correct the problems.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 190.

5.6A What water quality indicator is used as a rough measure of sedimentation basin process removal efficiency?

5.6B What problems can be created by a sudden increase in settled water turbidity?

5.7 STARTUP AND SHUTDOWN PROCEDURES

5.70 Conditions Requiring Implementation of Startup and Shutdown Procedures

Startup or shutdown of the sedimentation process is *NOT* a routine operating procedure in most water treatment plants that are operated on a continuous basis. Implementation of these procedures is generally associated with a complete plant shutdown for periodic maintenance and

TABLE 5.3 SEDIMENTATION PROCESS TROUBLESHOOTING

1. Source Water Quality Changes	Operator Actions	Possible Process Changes
• Turbidity • Temperature • Alkalinity • pH • Color	1. Perform necessary analyses to determine extent of change. 2. Evaluate overall process performance. 3. Perform jar tests if indicated. 4. Make appropriate process changes (see right hand column, Possible Process Changes). 5. Increase frequency of process monitoring. 6. Verify response to process changes at appropriate time (be sure to allow sufficient time for change to take effect).	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of sludge removal (increase or decrease). 5. Increase alkalinity by adding lime, caustic soda or soda ash.
2. Flocculation Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
• Turbidity • Alkalinity • pH	1. Evaluate overall process performance. 2. Perform jar tests if indicated. 3. Verify performance of coagulation-flocculation process (see Chapter 4, "Coagulation and Flocculation"). 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Adjust improperly working chemical feeder.
3. Sedimentation Basin Changes	**Operator Actions**	**Possible Process Changes**
• Floc Settling • Rising or Floating Sludge	1. Observe floc settling characteristics: a. Dispersion b. Size c. Settling rate 2. Evaluate overall process performance. 3. Perform jar tests if indicated: a. Assess floc size and settling rate. b. Assess quality of settled water (clarity and color). 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of sludge removal (increase or decrease). 5. Remove sludge from basin. 6. Repair broken sludge rakes.
4. Sedimentation Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
• Turbidity • Color	1. Evaluate overall process performance. 2. Perform jar tests if indicated. 3. Verify process performance: a. Coagulation-flocculation process (see Chapter 4, "Coagulation and Flocculation"). b. Floc settling characteristics. 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of sludge removal (increase or decrease).
5. Upflow Clarifier Process Effluent Quality Changes	**Operator Actions**	**Possible Process Changes**
• Turbidity	1. See 4 above.	1. See 4 above.
• Turbidity Caused by Sludge Blanket Coming to Top Due to Rainfall on Watershed	2. Open main drain valve of clarifier.	2. Drop entire water level of clarifier to bring the sludge blanket down.

cleaning, which is generally performed on an annual basis. In some instances, a shutdown may result from a major process failure. Photographs of special features provide a visual record of events or conditions which may be difficult to illustrate when basins are full of water.

5.71 Implementation of Startup/Shutdown Procedures

Typical actions performed by the operator in the startup or shutdown of the sedimentation process are outlined below.

5.710 Startup Procedures

1. Check operational status and mode of operation (manual or automatic) of equipment and physical facilities.
   a. Check that basin drain valves are closed.
   b. Check that basin isolation gates or stop logs are removed.
   c. Check that launder weir plates are set at equal elevations.
   d. Check to insure that all trash, debris and tools have been removed from basin.
2. Test sludge removal equipment.
   a. Check that mechanical equipment is properly lubricated and ready for operation.
   b. Observe operation of sludge removal equipment.
3. Fill sedimentation basin with water.
   a. Observe proper depth of water in basin.
   b. Remove floating debris from basin water surface.
4. Start sample pumps (allow sufficient flushing time before securing samples).
5. Perform water quality analyses (make process adjustments as necessary).
6. Operate sludge removal equipment. Be sure that all valves are in the proper position (either open or closed).

5.711 Shutdown Procedures

1. Stop flow to sedimentation basin. Install basin isolation gates or stop logs.
2. Turn off sample pumps.
3. Turn off sludge removal equipment.
   a. Shut off mechanical equipment and disconnect where appropriate.
   b. Check that valves are in proper position (either open or closed).
4. Lockout and tag electrical switches and equipment.
5. Dewater (drain) basin if necessary.
   a. Be sure water table is not high enough to float the empty basin.
   b. Open basin drain valves.
6. Grease and lubricate all gears, sprockets, and mechanical moving parts which have been submerged *IMMEDIATELY FOLLOWING DEWATERING*. If this is not done, they can freeze up (seize up) in a few hours. Frozen parts will require long hours to repair and can result in equipment breakage.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 190.

5.7A Under what circumstances might a water treatment plant have to be shut down?

5.7B List the shutdown procedures for a sedimentation basin.

5.7C Why should photographs be taken during shutdown and startup procedures?

5.8 LABORATORY TESTS

5.80 Process Control Water Quality Indicators

Process control water quality indicators of importance in the operation of the sedimentation process include turbidity and temperature.

5.81 Sampling Procedures

Process water samples will be either grab samples obtained directly from a specific process monitoring location, or continuous samples which are pumped to the laboratory from various locations in the process (flocculation basin effluent, settled water conduit). Process water samples must be representative of actual conditions in the treatment plant.

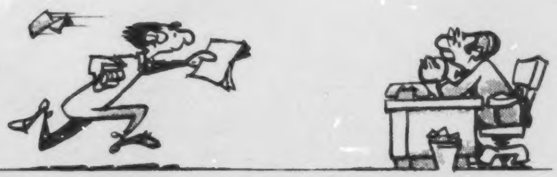
Critical water quality indicators such as turbidity will be routinely monitored, perhaps several times per eight-hour shift. Temperature will be evaluated less frequently, especially under stable water quality conditions.

Process grab samples should be collected in clean plastic or glass containers and care should be taken to avoid contamination of the sample.

Sample analysis should be performed immediately following sample collection. When this is not possible, care should be taken to preserve samples by proper storage. See Chapter 11, "Laboratory Procedures," for sample preservation and storage procedures.

5.82 Sample Analysis

Analysis of certain process control water quality indicators (such as turbidity) are easily performed in the laboratory with the aid of automated analytical instruments such as turbidimeters.



QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 190.

5.8A How are sedimentation process water samples obtained for analysis?

5.8B How frequently should you monitor the turbidity of the water being treated?

5.9 PROCESS AND SUPPORT EQUIPMENT OPERATION AND MAINTENANCE

5.90 Types of Equipment

The operator of a sedimentation process will need to be familiar with the operation and maintenance of a variety of mechanical, electrical, and electronic equipment including:

1. Sludge removal equipment,
2. Sludge pumps,
3. Sump pumps,
4. Valves,
5. Flow meters and gages,
6. Water quality monitors such as turbidimeters, and
7. Control systems.

Sludge removal equipment will constitute the majority of the electro-mechanical equipment used in the sedimentation process. Since a wide variety of systems can be used to effect removal of sludge from the bottom of the sedimentation basins, the operator will need to be thoroughly familiar with the operation and maintenance instructions for each specific equipment item.

5.91 Equipment Operation

Before starting a piece of mechanical equipment such as a sludge pump, be sure that the unit is properly lubricated and its operational status is known. After startup and during normal operation, check for excessive noise and vibration, overheating, and leakage (water, lubricants). Check the pump's suction and discharge pressures to be sure the lines are not plugged. When in doubt about the performance of a piece of equipment, always refer to the operation and maintenance instructions.

Many equipment items such as valves are simple open or closed devices, or sump pumps which are simple on/off devices. Other equipment such as sludge pumps have provisions for flow-rate adjustment and may be furnished with sight glasses to visually check sludge flow. Check the flow each time the equipment is operated. Sludge collectors, discharge lines, and troughs should be periodically flushed to maintain a free sludge flow. Calibration of flow rates and measurement of sludge density may require the use of special procedures. Detailed operating, repair, and calibration procedures are usually given in the manufacturer's literature.

5.92 Safety Considerations

To avoid accidents or injury when working around sludge removal equipment such as pumps and motors, follow the safety procedures listed below.

ELECTRICAL EQUIPMENT

1. Avoid electrical shock (use protective gloves),
2. Avoid grounding yourself in water or on pipes,
3. Ground all electrical tools,
4. Use the buddy system, and
5. Use a lockout and tag system whenever electrical equipment or electrically driven mechanical equipment is out of service or being worked on.

MECHANICAL EQUIPMENT

1. Keep protective guards on rotating equipment,
2. Do not wear loose clothing around rotating equipment,
3. Keep hands out of valves, pumps, and other pieces of equipment (lock out and tag power switches before cleaning),
4. Clean up all lubricant and sludge spills (slippery surfaces cause falls), and
5. Use a lockout and tag system whenever mechanical equipment is out of service or being worked on.

OPEN-SURFACE WATER-FILLED STRUCTURES

1. Use safety devices such as handrails and ladders,
2. Close all openings and replace safety gratings when finished working,
3. Know the location of all life preservers, and
4. Use the buddy system.

VALVE AND PUMP VAULTS, SUMPS

1. Be sure all underground or confined structures are free of hazardous atmospheres (use a gas detector to look for toxic or explosive gases, lack of sufficient oxygen),

2. Only work in well ventilated structures (use ventilation fans),
3. Use the buddy system, and
4. Lock or chain valves when working in an area that could be flooded.

5.93 Corrosion Control

The metallic parts of clarifiers and solids-contact units must be protected from corrosion. A good layer of paint or other protective coating over all metal parts exposed to water is one successful approach. Another approach is the use of a cathodic protection system (Figure 5.28).

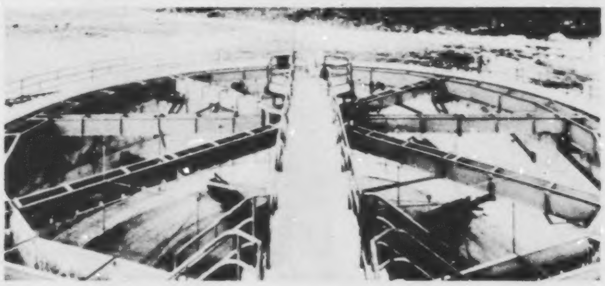


Fig. 5.28 Clarifier wired for cathodic protection
(Permission of Wallace and Tiernan Division of Pennwalt Corporation)

Cathodic protection is a process for reducing or eliminating corrosion of metal parts exposed to water, soil or the atmosphere. In this process the flow of an electrical current from the metal surface into water (the cause of corrosion) is stopped by overpowering it by applying a stronger current from another source (the cathodic protection system).

To maintain a high degree of corrosion control, you must inspect and test the operation of the cathodic protection system and its parts regularly. Regular and proper maintenance is critical because the amount of protective current required to prevent corrosion can vary with changes in the conditions of the coatings on the metallic surfaces, in the chemical characteristics of the water being treated, and the operation of the clarifier.

For additional information on how to control corrosion, see Chapter 8, "Corrosion Control."

5.94 Preventive Maintenance Procedures

Preventive maintenance (P/M) programs are designed to assure the continued satisfactory operation of treatment plant facilities by reducing the frequency of breakdown failures. This is accomplished by performing scheduled or routine maintenance of valves, pumps, and other electrical and mechanical equipment items.

In the normal operation of the sedimentation process, the operator will be expected to perform routine maintenance functions as part of an overall preventive maintenance program. Typical functions include:

1. Keeping electrical motors free of dirt and moisture,
2. Assuring good ventilation (air circulation) in equipment work areas,
3. Checking pumps and motors for leaks, unusual noise and vibrations, or overheating,
4. Maintaining proper lubrication and oil levels,
5. Inspecting for alignment of shafts and couplings,
6. Check bearings for overheating and proper lubrication,
7. Checking for proper valve operation (leakage or jamming), and
8. Checking for free flow of sludge in sludge removal collection and discharge systems.

Accurate records are a key element in a successful preventive maintenance program. These records provide maintenance and operations personnel with clues for determining causes for equipment breakdowns, and will assist in spotting similar weaknesses in other equipment items. The frequency of performing periodic maintenance on electrical and mechanical equipment items is often based on preventive maintenance records of prior performance, and equipment manufacturers' recommendations.

Good housekeeping practices are an important part of every preventive maintenance program.

For additional details on equipment maintenance, see Chapter 18, "Maintenance."

5.10 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read the following sections:

1. A.5 Weight-Volume Relations, and
2. A.134 Sedimentation.

Check all of the arithmetic in these two sections on an electronic pocket calculator. You should be able to get the same answers.

5.11 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 8, "Sedimentation."
2. *TEXAS MANUAL*, Chapter 8, "Coagulation and Sedimentation."

5.12 ACKNOWLEDGMENT

Many of the concepts and procedures discussed in this chapter are based on material obtained from the sources listed below.

1. Stone, B.G. Notes from "Design of Water Treatment Systems," CE-610, Loyola Marymount University, Los Angeles, CA, 1977.

2. *WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES*, American Water Works Association, Third Edition, McGraw-Hill, 1971. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10008, price to members, $34.10; nonmembers, $42.60.
3. *WATER TREATMENT PLANT DESIGN*, prepared jointly by the American Society of Civil Engineers, American Water Works Association, and Conference of State Sanitary Engineers, AWWA, 1969. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10006, price to members, $14.00; nonmembers, $18.00.
4. *OPERATION AND MAINTENANCE MANUAL FOR STOCKTON EAST WATER TREATMENT PLANT*, James M. Montgomery, Consulting Engineers, Inc., Walnut Creek, CA, 1979.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 190.

5.9A What possible items should be checked for after a sludge pump has been started?

5.9B How can a free sludge flow be maintained?

5.9C What types of safety hazards are associated with sludge removal equipment?

End of Lesson 2 of 2 Lessons
on
SEDIMENTATION

DISCUSSION AND REVIEW QUESTIONS

Chapter 5. SEDIMENTATION

(Lesson 2 of 2 Lessons)

Write your answers in a notebook and then compare your answers with those on page 191. The problem numbering continues from Lesson 1.

9. What would you check during a visual inspection of a sedimentation process?
10. How is the approximate process removal efficiency of a sedimentation basin determined?
11. What functions should be included in a sedimentation process preventive maintenance program?
12. What items should be checked when inspecting the condition of sludge removal equipment?
13. What process changes would you consider if source water quality abruptly changes?
14. How can the metallic parts of clarifiers be protected from corrosion?

SUGGESTED ANSWERS

Chapter 5. SEDIMENTATION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 151.

5.0A The purposes of the sedimentation process are to remove suspended solids (particles) that are denser (heavier) than the water and to reduce the load on the filters.

5.0B Sedimentation is accomplished by decreasing the velocity of the water being treated to allow heavier particles to settle out.

5.0C Presedimentation facilities are installed in locations where the source water supply is diverted directly from rivers or streams. The basins are especially needed if the rivers or streams can be contaminated by overland runoff and point source waste discharges.

Answers to questions on page 154.

5.1A Factors which affect particle settling in a sedimentation basin include: (1) particle size and distribution, (2) shape of particles, (3) density of particles, (4) temperature (viscosity and density) of water, (5) electrical charge on particles, (6) dissolved substances in water, (7) flocculation characteristics of the suspended material, (8) environmental conditions (wind), and (9) sedimentation basin hydraulic and design characteristics (inlet conditions and shape of basin).

5.1B Treatment is preferred before sedimentation to convert finer particles which do not readily settle into larger, denser particles (floc) that are settleable.

5.1C Types of currents that may be found in a typical sedimentation basin include: (1) surface currents induced by winds, (2) density currents caused by differences in suspended solids concentrations and temperature differences, and (3) eddy currents produced by the flow of the water coming into and leaving the basin.

Answers to questions on page 158.

5.2A The four zones into which a typical sedimentation basin can be divided are: (1) inlet zone, (2) settling zone, (3) sludge zone, and (4) outlet zone.

5.2B The purpose of the settling zone is to provide a calm, undisturbed storage place for the flocculated water for a sufficient time period to permit effective settling of the suspended particles in the water being treated.

5.2C Launders are skimming or effluent troughs used to uniformly collect settled water. Adjustable V-notch weirs are generally attached to the launders for controlling the water level in the sedimentation basin.

Answers to questions on page 166.

5.2D Sedimentation basins are available in circular, rectangular, or square shapes.

5.2E Double-deck sedimentation basins.

ADVANTAGES

1. Provide twice the surface area of a single basin of equivalent dimensions.
2. Conserve land area.

LIMITATIONS

1. Higher operation and maintenance costs.
2. Entire operation may have to be shut down if an equipment problem develops in either deck.

5.2F Rectangular sedimentation basins are often preferred over circular basins because circular basins are generally more sensitive to short-circuiting and poorer solids removal.

5.2G During the operation of a solids-contact unit, care must be exercised to assure that a uniform sludge blanket is formed, and is subsequently maintained throughout the solids removal process. Other important operational factors include control of chemical dosages, mixing of chemicals and control of sludge blanket.

Answers to questions on page 169.

5.2H The detention time is calculated by:

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})\,(24\text{ hr/day})}{\text{Surface Area, sq ft}}$$

5.2I

Known		Unknown
Flow, MGD	= 0.8 MGD	Detention Time, hr
Length, ft	= 50 ft	
Width, ft	= 20 ft	
Depth, ft	= 10 ft	

1. Calculate the basin volume in gallons.

$$\begin{aligned}\text{Basin Volume, gal} &= (\text{L, ft})\,(\text{W, ft})\,(\text{D, ft})\,(7.48\text{ gal/cu ft})\\ &= (50\text{ ft})\,(20\text{ ft})\,(10\text{ ft})\,(7.48\text{ gal/cu ft})\\ &= 74{,}800\text{ gallons}\end{aligned}$$

2. Determine the theoretical detention time in hours.

$$\begin{aligned}\text{Detention Time, hr} &= \frac{(\text{Basin Volume, gal})\,(24\text{ hr/day})}{\text{Flow, gal/day}}\\ &= \frac{(74{,}800\text{ gallons})\,(24\text{ hr/day})}{800{,}000\text{ gal/day}}\\ &= 2.2\text{ hours}\end{aligned}$$

Answers to questions on page 172.

5.2J Two advantages of solids-contact units include:

1. Only one reaction unit to contend with,
2. Ability to accumulate slurry during periods of severe taste and odor problems, and
3. Use slurry accumulation to carry plant when coagulation fails because of increased algal activities.

5.2K The level of the slurry or sludge blanket can be determined by sampling taps which are placed at various depths on the wall of the solids-contact reactor.

5.2L Operators should attempt to forecast turbidity changes and adjust chemical dosage prior to the arrival of a turbidity change.

Answers to questions on page 174.

5.2M The jar test is used to determine the proper chemical dose when operating a solids-contact unit. Observations and process monitoring are used to "fine tune" the results from jar tests.

5.2N Recirculation in a solids contact unit may be provided by impellers, turbines, pumping units or by air injection.

5.2O The percent slurry in the reaction zone is determined by the volume over volume (V/V) test.

Answers to questions on page 178.

5.2P Alum sludge solids concentrations typically vary from *0.25* to *10* percent when removed from a sedimentation basin.

5.2Q When determining how often to used sludge removal equipment, consider (1) the volume of sludge to be removed, (2) available sludge storage capacity, and (3) the fact that over 50 percent of the floc will settle out in the first third of the basin length. The sludge removal equipment will have to operate frequently enough to prevent excessive sludge buildup over the first third of the basin length.

5.2R Accumulated sludge must be removed periodically from the bottom of sedimentation basins to:

1. Prevent interference with the settling process (such as resuspension of solids due to scouring),
2. Prevent the sludge from becoming septic or providing an environment for the growth of microorganisms that can create taste and odor problems, and
3. Prevent excessive reduction in the cross-sectional area of the basin (reduction of detention time).

Answers to questions on page 179.

5.2S The depth of sludge in a sedimentation basin can be measured with a sludge blanket sounder, a bubbler tube, an aspirator, or an ultrasonic level indicator.

5.2T If the sludge being pumped from a sedimentation basin is too low in solids (soupy), the frequency of sludge removal should be decreased.

Answers to questions on page 179.

5.3A Sedimentation basins are needed to treat water when source water turbidities are high and generally require alum dosage for efficient solids removal.

5.4A The two major factors that influence the performance of sedimentation basins are (1) the settling characteristics of the suspended particles, and (2) the flow rate through the sedimentation basins.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 183.

5.5A During the normal operation of the sedimentation process the operator should monitor settled water turbidity and should visually observe the settling rate of floc particles and the clarity of the water spilling over the launder weirs. Other items include visual verification that a uniform water depth of water is spilling over the effluent launder weirs, and that sludge removal lines are free flowing.

5.5B Visual observations and laboratory evaluation of sedimentation process performance should be conducted on a routine basis, at least one per eight-hour shift, and more frequently when water quality conditions are fluctuating.

5.5C Free-flowing sludge can be readily observed if sight glasses are incorporated in the sludge discharge piping. Otherwise, the outlet of the sludge line should be observed during sludge pumping.

5.5D Frequent clogging of the sludge discharge line is an indication that the sludge concentration is too high. If this occurs, try increasing the frequency of operation of the sludge removal equipment.

5.5E In the routine operation of the sedimentation process, the following records should be maintained: (1) process water quality, (2) process production inventory, and (3) process equipment performance.

Answers to questions on page 183.

5.6A The measurement of turbidity levels at the sedimentation basin inlet and outlet will give a rough idea of process removal efficiency.

5.6B Sudden increases in settled water turbidity could cause problems in the operation of the filtration process. High settled water turbidity levels resulting from floc carryover from the sedimentation basin will cause premature clogging of filters and may result in the degradation of filtered water quality.

Answers to questions on page 185.

5.7A A water treatment plant might have to be shut down for periodic maintenance and cleaning, or from a major process failure.

5.7B Shutdown procedures for a sedimentation basin include:

1. Stop flow to sedimentation basin. Install basin isolation gates or stop logs.
2. Turn off sample pumps.
3. Turn off sludge removal equipment.
   a. Shut off mechanical equipment.
   b. Check that valves are in proper position.
4. Dewater (drain) basin if necessary.
   a. Be sure water table is not high enough to float the empty basin.
   b. Open basin drain valves.

5.7C Photographs of special features during startup and shutdown provide a visual record of events or conditions which may be difficult to illustrate when basins are full of water.

Answers to questions on page 186.

5.8A Sedimentation process water samples may be either grab samples obtained directly from a specific process monitoring location, or continuous samples which are pumped to the laboratory from various locations in the process.

5.8B Turbidity should be measured several times during a shift and more frequently when the source water quality is changing rapidly.

Answers to questions on page 188.

5.9A After a sludge pump has been started, always check for excessive noise and vibration, overheating, and leakage (water, lubricants). Also check the suction and discharge pressures to be sure the lines are not plugged.

5.9B A free sludge flow can be maintained by periodically flushing sludge collectors, discharge lines and troughs. Correct operation of the sedimentation basin will usually result in a free sludge flow.

5.9C Types of safety hazards associated with sludge removal equipment include: (1) electrical equipment, (2) mechanical equipment, (3) open-surface water-filled structures, and (4) valve and pump vaults, sumps.

OBJECTIVE TEST

Chapter 5. SEDIMENTATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each multiple choice question.

TRUE-FALSE

1. When water temperatures increase, the flow through a sedimentation basin must be decreased.
   1. True
   2. False

2. Sedimentation basin covers to prevent wind currents are desirable from an operations and maintenance standpoint.
   1. True
   2. False

3. There is no difference between high-rate settlers and tube settlers.
   1. True
   2. False

4. In theory, the ideal sedimentation basin would have a shallow depth and a large surface area.
   1. True
   2. False

5. The detention time may be defined as the actual time that a small amount of water is retained in the sedimentation basin.
   1. True
   2. False

6. From a water quality standpoint, filter effluent turbidity provides a good indication of overall process performance.
   1. True
   2. False

7. Good recordkeeping is an important element of the communication process.
   1. True
   2. False

8. Water temperature changes may require that jar tests be performed to establish optimum floc settling rates.
   1. True
   2. False

9. Emergency response procedures should contain current names and telephone numbers of persons to be notified under specific conditions.
   1. True
   2. False

10. Startup and shutdown of the sedimentation process is a routine operating procedure in most water treatment plants that are operated on a continuous basis.
    1. True
    2. False

MULTIPLE CHOICE

11. Zones found in a typical rectangular sedimentation basin include the
    1. Flotation zone.
    2. Inlet zone.
    3. Outlet zone.
    4. Settling zone.
    5. Sludge zone.

12. Types of sedimentation basins include
    1. Circular.
    2. Double-deck.
    3. Flocculation.
    4. Rectangular.
    5. Square.

13. A chemical application point should be provided in the settled water conduit between the sedimentation basin and the filter to permit the feeding of ____________ chemicals.
    1. Coagulation
    2. Corrosion control
    3. Filter aid
    4. Flocculation
    5. Scouring

14. What problems are created when the sludge buildup on the bottom of the sedimentation basin becomes too great?
    1. Degradation of process efficiency will result
    2. Demand for coagulation chemicals will increase
    3. Effective depth of the basin will be reduced
    4. Localized high flow velocities will be produced
    5. Sludge scouring will occur

15. What problems could develop if sludge is allowed to remain too long and build up on the bottom of a sedimentation basin?
    1. Creation of taste and odor problems
    2. Degradation of process efficiency
    3. Reduction of detention time
    4. Resuspension of solids due to scouring
    5. Sludge becomes septic

16. If adequate detention time and basin surface area are provided, what is the highest possible sedimentation basin removal efficiency that can be achieved?
    1. 20%
    2. 35%
    3. 50%
    4. 75%
    5. 95%

17. Visual inspection of the sedimentation process should include observation of
    1. Clarity of settled water spilling over the launder weirs.
    2. Distribution of floc at the basin inlet.
    3. Floc settling characteristics.
    4. Residual chlorine concentration in the effluent launders.
    5. Temperature of the water being treated.

18. When inspecting the condition of sludge removal equipment, operators should check for
    1. Leakage.
    2. Noise.
    3. Overheating.
    4. Vibration.
    5. Worn parts.

19. In a sedimentation basin, the detention time is the ____________ time that a small amount of water is in the basin.
    1. Actual
    2. Calculated
    3. Flocculation
    4. Mixing
    5. Theoretical

20. If source water turbidity suddenly changes, what process changes should the operator consider?
    1. Adjust coagulant dosage
    2. Adjust flocculation mixing intensity
    3. Change coagulant
    4. Change frequency of sludge removal
    5. Decrease or increase flow of water being treated

21. Process control water quality indicators that are important in the operation of the sedimentation process include
    1. Alkalinity.
    2. Chlorine demand.
    3. Coliforms.
    4. pH.
    5. Turbidity.

22. When treating extremely cold water in a solids-contact unit, you may consider increasing the chemical dosages by the use of
    1. Activated silica.
    2. Alum.
    3. Ferric chloride.
    4. Polymers.
    5. Powdered calcium carbonate.

23. Fundamental principles that make a solids-contact unit function properly include
    1. Chemical dosage.
    2. Flocculation stirring.
    3. Particle settling velocity.
    4. Recirculation.
    5. Sludge control.

24. When using alum as a coagulant, alkalinity can be added to water by using
    1. Caustic soda.
    2. Citric acid.
    3. Lime.
    4. Soda ash.
    5. Sodium chloride.

25. Factors which influence the frequency of sludge removal from a sedimentation basin include
    1. Amount of suspended material and floc removal.
    2. Capacity of sludge pump.
    3. pH of water.
    4. Size of sludge dewatering pond.
    5. Size of sludge pump.

26. When operating a solids-contact unit, operational factors of concern include
    1. Adjustment of water temperature.
    2. Control of chemical dosage.
    3. Control of sludge blanket.
    4. Maintenance of a uniform sludge blanket.
    5. Speed of flocculators.

27. Calculate the theoretical detention time for a rectangular sedimentation basin. The basin is 70-feet long, 30-feet wide, 12-feet deep and treats a flow of 1.4 MGD.
    1. 2.2 hours
    2. 2.5 hours
    3. 2.7 hours
    4. 3.0 hours
    5. 3.2 hours

28. A tank with a capacity of 5000 cubic feet can hold how many gallons of water?
    1. 600 gallons
    2. 670 gallons
    3. 6,700 gallons
    4. 37,400 gallons
    5. 41,700 gallons

29. A tank with a capacity of 80 cubic feet can hold how many pounds of water?
    1. 600 pounds
    2. 670 pounds
    3. 4990 pounds
    4. 6000 pounds
    5. 6700 pounds

30. If a tank holds 1000 pounds of water, how many gallons of water are in the tank?
    1. 16 gallons
    2. 120 gallons
    3. 134 gallons
    4. 7,500 gallons
    5. 8,340 gallons

END OF OBJECTIVE TEST

APPENDIX

A. Design and Operational Guidelines
  1. Surface Loading
  2. Effective Water Depth
  3. Mean Flow Velocity
  4. Weir Loading

A. DESIGN AND OPERATIONAL GUIDELINES

Some of the basic guidelines used by engineers to design sedimentation processes are described in this section. Operators should know how these guidelines are obtained and why they are important in order to communicate effectively with design engineers.

By knowing the values used by design engineers and comparing the actual values for your plant, you may be able to identify the cause of operational problems and poor quality finished water.

Detention time is a very important guideline used by designers; however, this topic has already been discussed in Section 5.23, "Detention Time," and will not be repeated again.

1. Surface Loading

Surface loading or overflow rate is one of the most important factors influencing sedimentation. The surface overflow rate translates into a velocity, and it is equal to the settling velocity of the smallest particle which the basin will remove.

Surface loading is determined by dividing basin flow rate by the basin surface area as follows:

$$\text{Surface Loading, GPM/sq ft} = \frac{\text{Flow, Gallons Per Minute}}{\text{Surface Area, square feet}}$$

Colder water temperatures require lower basin overflow rates since particle settling velocities also decrease with colder water temperatures. Therefore, your plant can effectively treat only lower flow rates during colder weather. The overflow rate is the same as the theoretical upwelling rate. When this value exceeds the settling rate of a particle, the particle will be unable to settle out and will be carried over to the filters.

EXAMPLE 1

A water treatment plant treats a flow of 1.5 MGD. An examination of treatment plant design drawings reveals that the rectangular sedimentation basin is 75-feet long, 25-feet wide and has an effective (water) depth of 12 feet. Calculate the surface loading or overflow rate in gallons per minute per square foot of surface area.

Known	Unknown
Flow, MGD = 1.5 MGD	Surface Loading, GPM/sq ft
Length, ft = 75 ft	
Width, ft = 25 ft	
Depth, ft = 12 ft	

1. Convert flow in MGD to GPM.

$$\text{Flow, GPM} = (\text{Flow, MGD})\left(\frac{1{,}000{,}000}{(1\ \text{Million})(24\ \text{hr/day})(60\ \text{min/hr})}\right)$$

$$= (1.5\ \text{MGD})\left(\frac{1{,}000{,}000}{(1\ \text{Million})(24\ \text{hr/day})(60\ \text{min/hr})}\right)$$

$$= 1041\ \text{GPM}$$

2. Determine the surface loading in gallons per minute per square foot of surface area.

$$\text{Surface Loading, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$= \frac{1041\ \text{GPM}}{(75\ \text{ft})(25\ \text{ft})}$$

$$= 0.56\ \text{GPM/sq ft}$$

The surface loading or overflow rate can be converted to a rise rate in feet per minute by dividing the surface loading by 7.48 gallons per cubic foot.

$$\text{Rise Rate, ft/min} = \frac{\text{Surface Loading, GPM/sq ft}}{(7.48\ \text{gal/cu ft})}$$

EXAMPLE 2

A solids-contact unit has a surface loading rate of 0.75 GPM/sq ft. What is the rise rate in feet per minute?

Known	Unknown
Surface Loading, GPM/sq ft = 0.75 GPM/sq ft	Rise Rate, ft/min

Calculate the rise rate in feet per minute from the surface loading.

$$\text{Rise Rate, ft/min} = \frac{\text{Surface Loading, GPM/sq ft}}{7.48\ \text{gal/cu ft}}$$

$$= \frac{0.75\ \text{GPM/sq ft}}{7.48\ \text{gal/cu ft}}$$

$$= 0.1\ \text{ft/min}$$

2. Effective Water Depth

In theory, the ideal sedimentation basin would have a very shallow depth and a large surface area. However, practical considerations such as minimum depth required to accommodate mechanical sludge removal equipment, desired flow velocity, and current and wind effects, must all be considered in the selection of an appropriate basin depth.

Sludge volume storage requirements may also be an important consideration in selecting an appropriate basin depth. This is particularly important in manually cleaned basins where sludge removal requires taking the basin off-line for dewatering (draining) to permit removal of accumulated sludge. If the sludge buildup becomes too great, the effective depth of the basin will be significantly reduced. This can cause localized high flow velocities, sludge scouring, and degradation of process efficiency.

3. Mean Flow Velocity

The flow velocity is a function of the basin cross-sectional area and the flow going into the basin. Flow velocity is calculated by dividing the flow rate by the cross-sectional area of the basin.

The flow velocity is not completely uniform or stable throughout the length of the basin due to variations in water density, currents, and reduction in cross-sectional area resulting from sludge accumulation in the bottom of the basin.

The main concern about high velocities is scour. When velocities get too high, the flowing water will pick up some of the settled sludge from the bottom of the basin and carry it on to the filters. This is called "scour," and it reduces sedimentation efficiency.

$$\text{Mean Flow Velocity, ft/min} = \frac{\text{Flow, GPM}}{(\text{Cross-Sectional Area, sq ft})(7.48\text{ gal/cu ft})}$$

EXAMPLE 3

Determine the mean flow velocity in feet per minute for the rectangular sedimentation basin in EXAMPLE 1.

Known		Unknown
Flow, MGD	= 1.5 MGD	Mean Flow Velocity, ft/min
	= 1041 GPM	
Length, ft	= 75 ft	
Width, ft	= 25 ft	
Depth, ft	= 12 ft	

1. Determine the mean flow velocity in feet per minute.

$$\text{Mean Flow Velocity, ft/min} = \frac{\text{Flow, GPM}}{(\text{Cross-Sectional Area, sq ft})(7.48\text{ gal/cu ft})}$$

$$= \frac{(1041\text{ gal/min})}{(25\text{ ft})(12\text{ ft})(7.48\text{ gal/cu ft})}$$

$$= 0.46\text{ ft/min}$$

4. Weir Loading Rate

Launders outfitted with V-notch weirs are generally installed at the basin outlet to provide uniform collection and distribution of the clear water. While insufficient total weir length may reduce settling efficiency due to current effects, operation over a broad range of weir loading rates will generally not interfere with basin performance. If the weir loading rate becomes too high, floc will be carried out of the sedimentation basins and onto the filters. Generally, weir loadings are more important in shallow basins than in deeper basins.

In cold climates launders use orifices in pipes rather than V-notch weirs on channels. Pipes are submerged in two feet (0.6 m) of water to avoid ice problems.

$$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Weir Length, ft}}$$

EXAMPLE 4

Determine the weir loading rate in gallons per minute per foot of weir of the rectangular sedimentation basin in EXAMPLE 1. Four effluent launders 12.5-feet long with V-notch weirs on both sides of the launder extend into the basin from the outlet end. Therefore, each launder has 25 feet of weir for a total of 100 feet.

Known		Unknown
Flow, MGD	= 1.5 MGD	Weir Loading Rate, GPM/ft
	= 1041 GPM	
Length, ft	= 75 ft	
Width, ft	= 25 ft	
Depth, ft	= 12 ft	
Weir Length, ft	= 100 ft	

1. Calculate the weir loading rate in gallons per minute per foot of weir.

$$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Weir Length, ft}}$$

$$= \frac{1041\text{ GPM}}{100\text{ ft}}$$

$$= 10.4\text{ GPM/ft}$$

CHAPTER 6

FILTRATION

by

Jim Beard

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OBJECTIVES

Chapter 6. FILTRATION

Following completion of Chapter 6, you should be able to:

1. Describe the various types of potable water filters and how they work,
2. Explain how other treatment processes affect the performance of the filtration process,
3. Operate and maintain filters under normal and abnormal process conditions,
4. Start up and shut down filtration processes, and
5. Safely perform duties related to the various types of filters.

GLOSSARY

Chapter 6. FILTRATION

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ACTIVATED CARBON ACTIVATED CARBON

Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water.

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AIR BINDING AIR BINDING

A situation where air enters the filter media. Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

BACKWASHING BACKWASHING

The process of reversing the flow of water back through the filter media to remove the entrapped solids.

BASE METAL BASE METAL

A metal (such as iron) which reacts with dilute hydrochloric acid to form hydrogen. Also see NOBLE METAL.

BREAKTHROUGH BREAKTHROUGH

A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter effluent turbidity. A breakthrough can occur (1) when a filter is first placed in service, (2) when the effluent valve suddenly opens or closes, and (3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).

COLLOIDS (CALL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

CONVENTIONAL FILTRATION CONVENTIONAL FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called COMPLETE FILTRATION. Also see DIRECT FILTRATION and IN-LINE FILTRATION.

CONVENTIONAL TREATMENT CONVENTIONAL TREATMENT

See CONVENTIONAL FILTRATION. Also called COMPLETE TREATMENT.

DIATOMACEOUS EARTH (DYE-uh-toe-MAY-shus) DIATOMACEOUS EARTH

A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms.

DIATOMS (DYE-a-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid (box-like) internal structure consisting mainly of silica.

DIRECT FILTRATION DIRECT FILTRATION

A method of treatment water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted. Also see CONVENTIONAL FILTRATION and IN-LINE FILTRATION.

EFFECTIVE SIZE (E.S.) EFFECTIVE SIZE (E.S.)

The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger, on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

FLUIDIZED (FLEW-id-I-zd) FLUIDIZED

A mass of solid particles that is made to flow like liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by backwashing water through the filter.

GARNET (GAR-nit) GARNET

A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron, and manganese). Garnet has a higher density than sand.

HEAD LOSS HEAD LOSS

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses. The head loss through a filter is due to friction losses caused by material building up on the surface or in the top part of a filter.

IN-LINE FILTRATION IN-LINE FILTRATION

The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pretreatment method is commonly used in pressure filter installations. Also see CONVENTIONAL FILTRATION and DIRECT FILTRATION.

INTERFACE INTERFACE

The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

NOBLE METAL NOBLE METAL

A chemically inactive metal (such as gold). A metal that does not corrode easily and is much scarcer (and more valuable) than the so-called useful or base metals. Also see BASE METAL.

PERMEABILITY (PURR-me-uh-BILL-uh-tee) PERMEABILITY

The property of a material or soil that permits considerable movement of water through it when it is saturated.

PORE PORE

A very small open space in a rock or granular material.

SLURRY (SLUR-e) SLURRY

A watery mixture or suspension of insoluble (not dissolved) matter; a thin water mud or any substance resembling it (such as a grit slurry or a lime slurry).

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle, substance, or chemical solution in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (or 39°F). Particulates in raw water may have a specific gravity of 1.005 to 2.5.

SUBMERGENCE SUBMERGENCE

The distance between the water surface and the media surface in a filter.

TURBIDIMETER TURBIDIMETER

An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

UNIFORMITY COEFFICIENT (U.C.) UNIFORMITY COEFFICIENT (U.C.)

Uniformity coefficient is the ratio of these two measurements:

(1) The diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, and

(2) The diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through.

The resulting ratio is a measure of the degree of uniformity in a granular material such as filter media.

CHAPTER 6. FILTRATION

(Lesson 1 of 2 Lessons)

6.0 PROCESS DESCRIPTION

The purpose of filtration is the removal of particulate impurities and floc from the water being treated. Filtration is the process of passing water through material such as a bed of sand, coal, or other granular substance to remove floc and particulate impurities. These impurities consist of suspended particles (fine silts and clays), *COLLOIDS,*[1] biological forms (bacteria and plankton), and floc in the water being treated.

Filtration preceded by coagulation, flocculation, and sedimentation is commonly referred to as *CONVENTIONAL FILTRATION* (Fig. 6.1). In the *DIRECT FILTRATION* process, the sedimentation step is omitted. Typical treatment processes for each of these filtration methods are shown in Figure 6.2.

6.1 FILTRATION MECHANISMS

Filtration is essentially a physical and chemical process. The actual removal mechanisms are interrelated and rather complex, but filter removal of turbidity is based on the following factors:

1. Chemical characteristics of the water being treated (particularly source water quality),
2. Nature of suspension (physical and chemical characteristics of particulates suspended in the water),
3. Types and degree of pretreatment (coagulation, flocculation, and sedimentation), and
4. Filter type and operation.

A popular misconception is that particles are removed in the filtration process mainly by physical *STRAINING*. Straining is a term used to describe the removal of particles from a liquid (water) by passing the liquid through a filter whose *PORES*[2] are smaller than the particles to be removed. While the straining mechanism does play a role in the overall removal process, especially in the removal of larger particles, it is important to realize that most of the particles removed during filtration are considerably smaller than the pore spaces in the media. This is particularly true at the beginning of the filtration cycle when the pore spaces are clean (not clogged by particulates removed during filtration).

Thus, a number of interrelated removal mechanisms within the filter media itself are relied upon to achieve high removal efficiencies. These removal mechanisms include the following processes:

1. Sedimentation on media (very important),
2. *ADSORPTION*[3] (very important),
3. Biological action,
4. *ABSORPTION*[4] (not too important after initial wetting), and
5. Straining.

The relative importance of these removal mechanisms will depend largely on the nature of the water being treated, degree of pretreatment, and filter characteristics.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 240.

6.0A What is the major difference between conventional filtration and direct filtration?

6.1A List the particle removal mechanisms involved in the filtration process.

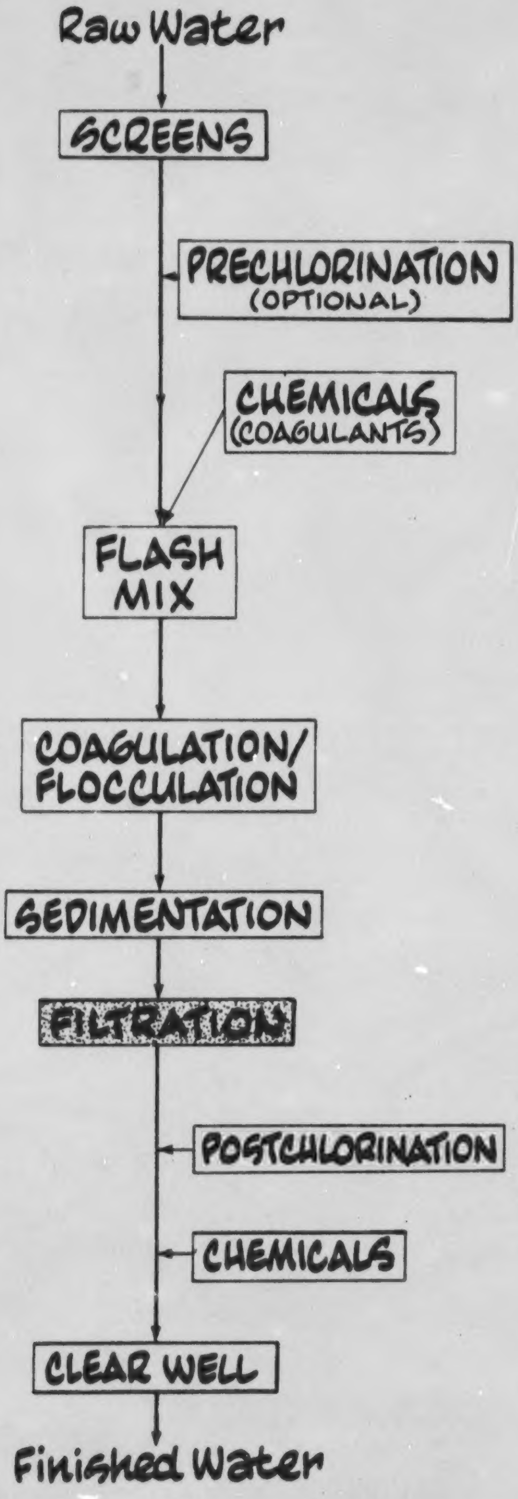
---

[1] *Colloids (CALL-loids). Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.*

[2] *Pore. A very small open space in a rock or granular material.*

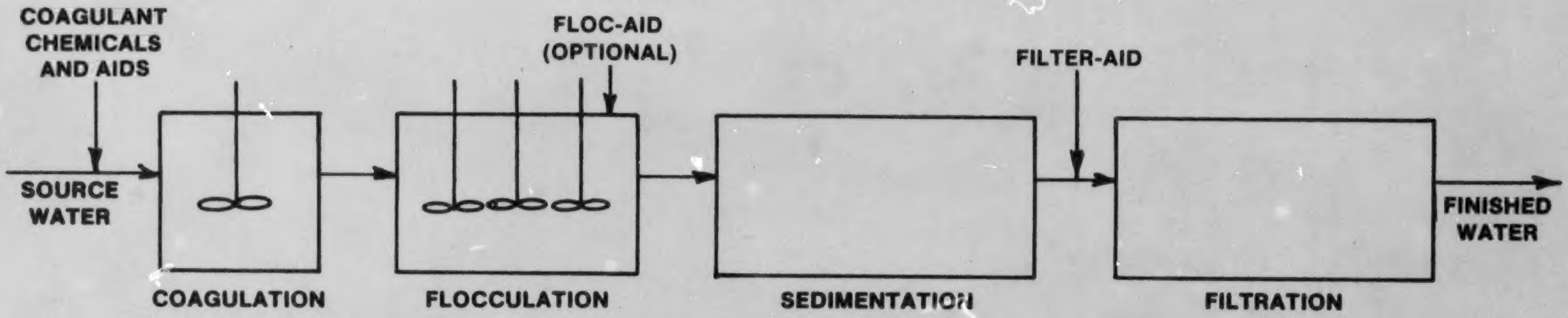
[3] *Adsorption (add-SORP-shun). The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.*

[4] *Absorption (ab-SORP-shun). Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).*

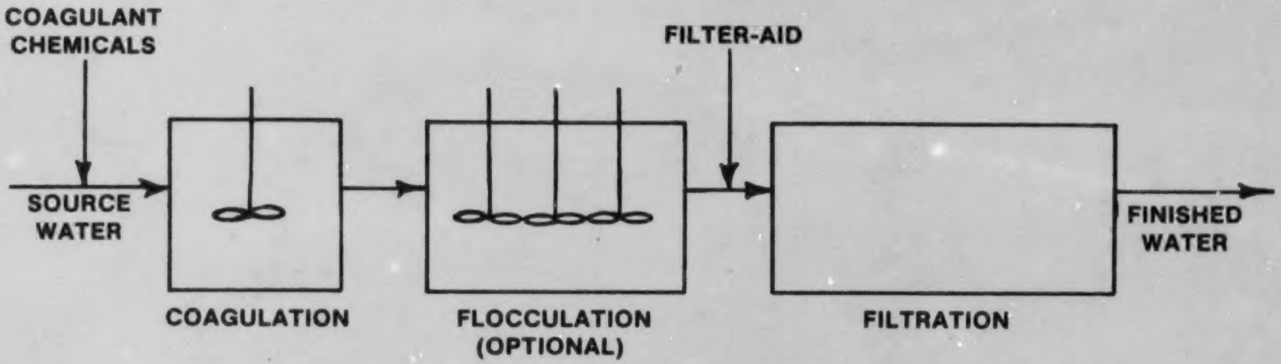


TREATMENT PROCESS	PURPOSE
Raw Water	
SCREENS	Removes leaves, sticks, fish & other large debris.
PRECHLORINATION (OPTIONAL)	Kills most disease causing organisms & helps control taste and odor causing substances.
CHEMICALS (COAGULANTS)	Causes very fine particles to clump together into larger particles.
FLASH MIX	Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water.
COAGULATION/ FLOCCULATION	Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration processes.
SEDIMENTATION	Settles out larger suspended particles.
FILTRATION	Filters out remaining suspended particles.
POSTCHLORINATION	Kills disease-causing organisms. Provides chlorine residual for distribution system.
CHEMICALS	Controls corrosion.
CLEAR WELL	Provides chlorine contact time for disinfection. stores water for high demand.
Finished Water	

Fig. 6.1 Typical process flow diagram


COAGULANT CHEMICALS AND AIDS
SOURCE WATER
COAGULATION
FLOC-AID (OPTIONAL)
FLOCCULATION
SEDIMENTATION
FILTER-AID
FILTRATION
FINISHED WATER

CONVENTIONAL FILTRATION


COAGULANT CHEMICALS
SOURCE WATER
COAGULATION
FLOCCULATION (OPTIONAL)
FILTER-AID
FILTRATION
FINISHED WATER

DIRECT FILTRATION

Fig. 6.2 Water treatment filtration processes

6.2 TYPES OF FILTERS

Over the years a distinction has been made between the older *SLOW SAND FILTRATION* process (minor application in the United States) and modern *RAPID SAND FILTRATION* (used extensively in the United States). This distinction is made because the removal mechanisms which apply to slow sand filtration are not directly comparable to those used in rapid sand filtration. However, the rapid sand process has taken on new dimensions in recent years owing to significant improvements in the process. The term "rapid sand filtration" no longer adequately describes the variety of processes used. Thus, a more specific classification system for filter types has developed, and includes the following:

1. Gravity filtration (sand, dual media, and mixed media),
2. Pressure filtration (mixed media),
3. *DIATOMACEOUS EARTH*[5] (precoat) filtration, and
4. Slow sand filtration.

6.20 Gravity Filtration

In all gravity filtration systems the water level or pressure (head) above the media forces the water through the filter media as shown in Figure 6.3. The rate at which water passes through the granular filter media may vary from 2 to about 10 GPM/sq ft (1.36 to 6.79 liters per sec/sq m or 1.36 to 6.79 mm/sec)[6] (commonly referred to as filtration rate). However, many state health authorities limit the maximum filtration rate to 2 or 3 GPM/sq ft (1.36 or 2.04 liters per sec/sq m or 1.36 to 2.04 mm/sec) for gravity filtration. The rate of water flow through the filter is the hydraulic loading or merely the filtration rate. The filtration rate depends on the type of filter media.

Filter medial consists of the following substances:

1. Single media (sand),[7]
2. Dual media (sand and anthracite coal), and
3. Mutli or mixed media (sand, anthracite coal, and *GARNET*[8]).

ACTIVATED CARBON[9] can also be used along with the above filter media for removal of tastes, odors, and organic substances.

In gravity filtration the particulate impurities are removed in/on the media, thus causing the filter to clog after a period of filtration time. In spite of this, gravity filtration is very widely used in water treatment plants.

6.21 Pressure Filtration

A pressure filter is similar to a gravity sand filter except that the filter is completely enclosed in a pressure vessel such as a steel tank, and is operated under pressure, as shown in Figure 6.4.

Pressure filters frequently offer lower installation and operation costs in small filtration plants; *HOWEVER*, they are generally somewhat less reliable than gravity filters (depending upon pumped pressure). Some states do not recommend the use of pressure filters for treating surface waters.

6.22 Diatomaceous Earth Filtration

In diatomaceous earth (precoat) filtration the filter media is added to the water being treated as a *SLURRY*;[10] it then collects on a septum (a pipe or conduit with porous walls) or other appropriate screening device as shown in Figure 6.5. After the initial precoat application, water is filtered by passing it through the coated screen. The coating thickness may be increased during the filtration process by gradually adding more media — a body feed. In most water treatment applications diatomaceous earth is used for both the precoat and body-feed operations.

Diatomaceous earth filtration is primarily a straining process, and finds wide application where very high particle removal efficiences (high clarity water) are required, such as in the beverage and food industries. Precoat filters can be operated as gravity, pressure or vacuum filters. They are also commonly used in swimming pool installations due to their small size, efficiency, ease of operation and relatively low cost. They find limited use in larger water treatment plants due to hydraulic (flow), sludge disposal, and other operational considerations.

6.23 Slow Sand Filtration

In slow sand filtration, water is drawn through the filter media (sand) by gravity as it is in the gravity filtration process. However, this is generally where the similarity between these two filtration processes ends.

In the slow sand filtration process, particles are removed by straining, adsorption, and biological action. Filtration rates are extremely low (0.015 to 0.15 GPM/sq ft or 0.01 to 0.1 liters per sec/sq m or 0.01 to 0.1 mm/sec).

The majority of the particulate material is removed in the top several inches of sand, so this entire layer must be physically removed when the filter becomes clogged. This filtration process has found limited application due to the large area required and the need to manually backwash the filters.

---

[5] *Diatomaceous Earth (DYE-uh-toe-MAY-shus). A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms.*

[6] *Note that the numbers for liters per second per square meter are the same as for millimeters per second.*

$$1\ \frac{\text{liter per sec}}{\text{square meter}} = \frac{(1\ \text{liter/sec})\ (1\ \text{cu meter})\ (1000\ \text{mm})}{(\text{square meter})\ (1000\ \text{liters})\ (1\ \text{meter})}$$

$$= 1\ \text{mm/sec.}$$

This occurs because one cubic meter equals 1000 liters and one meter equals 1000 millimeters.

[7] *Single media filters also may consist of either anthracite coal or granular activited carbon.*

[8] *Garnet (GAR-nit). A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron, and manganese). Garnet has a higher density than sand.*

[9] *Activated Carbon. Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water.*

[10] *Slurry (SLUR-e). A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).*

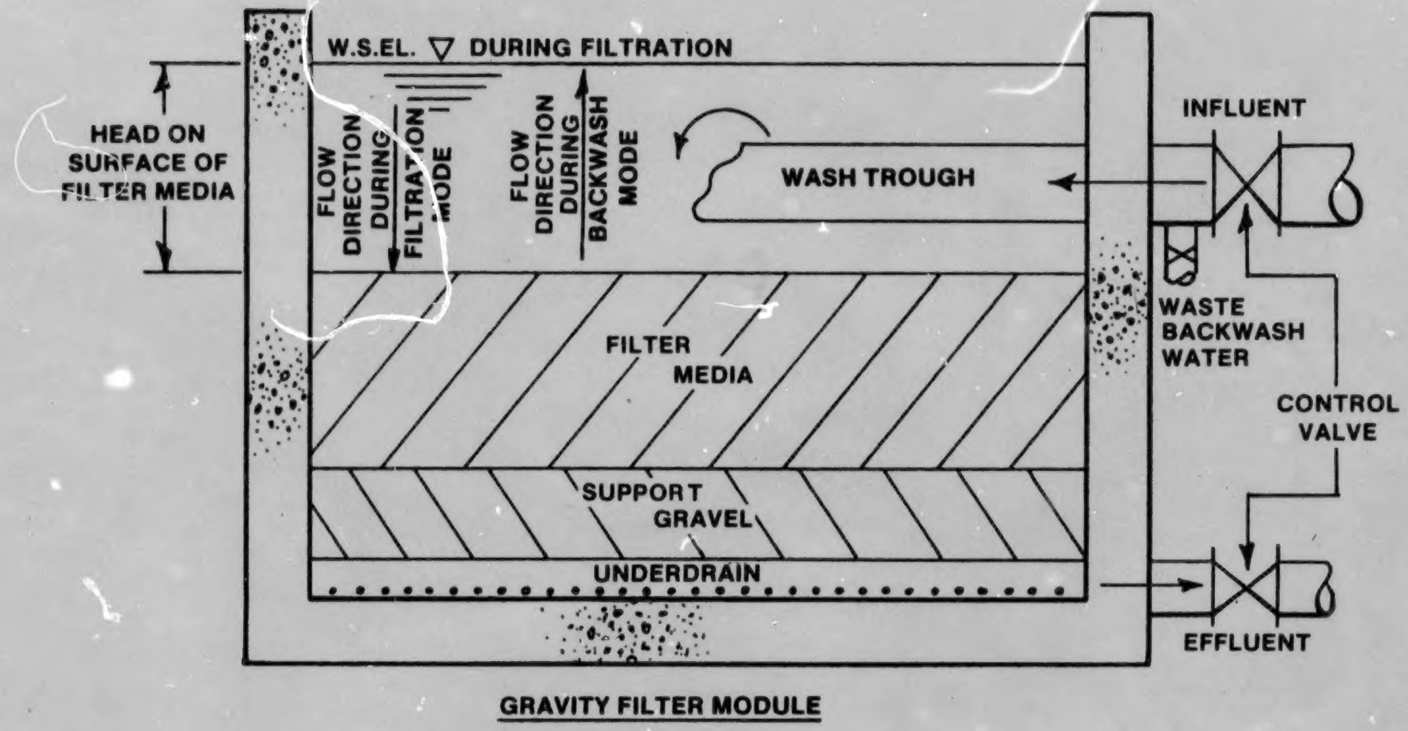

W.S.EL. ▽ DURING FILTRATION
HEAD ON SURFACE OF FILTER MEDIA
FLOW DIRECTION DURING FILTRATION MODE
FLOW DIRECTION DURING BACKWASH MODE
WASH TROUGH
INFLUENT
WASTE BACKWASH WATER
CONTROL VALVE
FILTER MEDIA
SUPPORT GRAVEL
UNDERDRAIN
EFFLUENT
GRAVITY FILTER MODULE

Fig. 6.3 Gravity filter

223

224

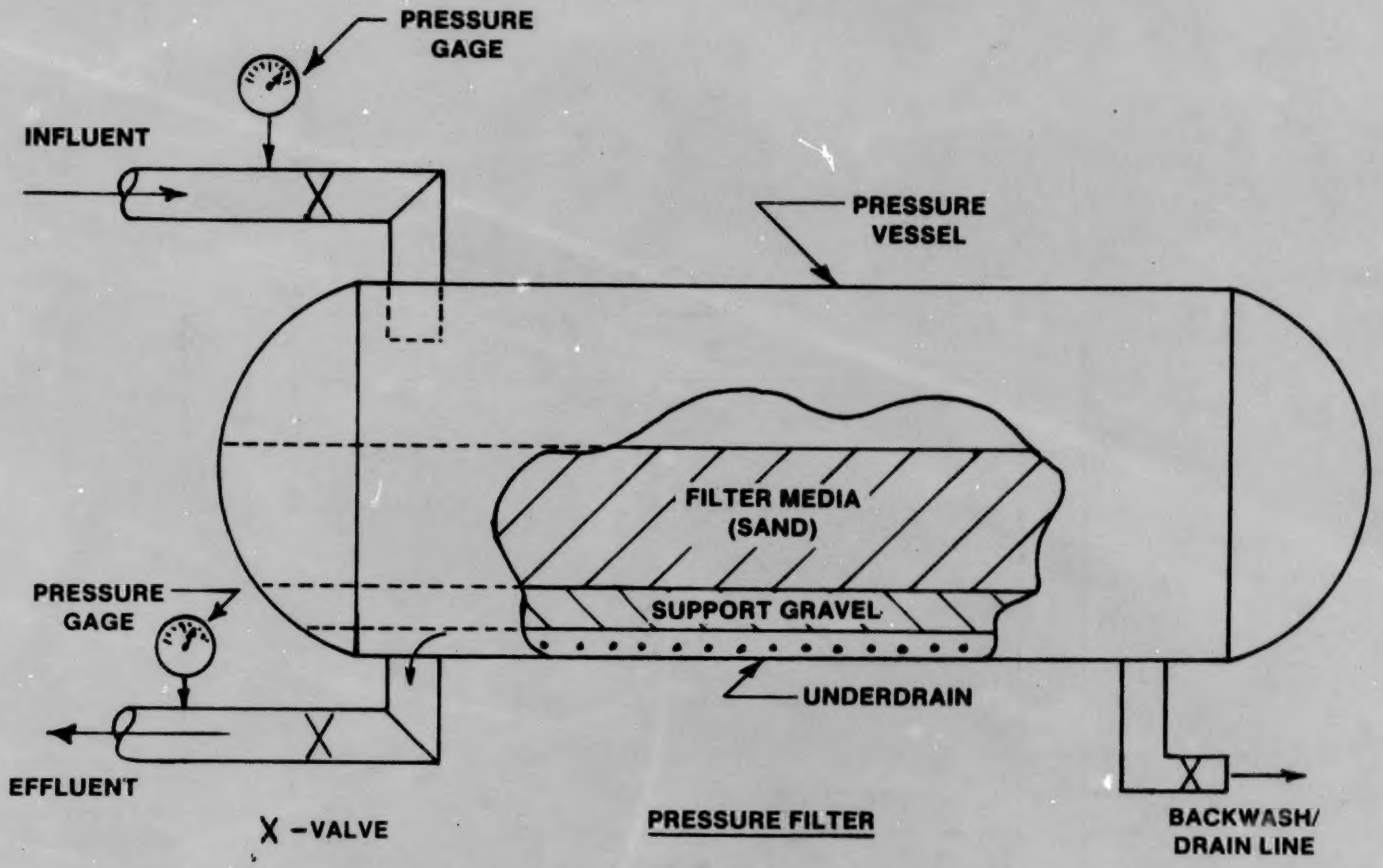

PRESSURE GAGE
INFLUENT
PRESSURE VESSEL
FILTER MEDIA (SAND)
PRESSURE GAGE
SUPPORT GRAVEL
UNDERDRAIN
EFFLUENT
X –VALVE
PRESSURE FILTER
BACKWASH/ DRAIN LINE

Fig. 6.4 Pressure filter

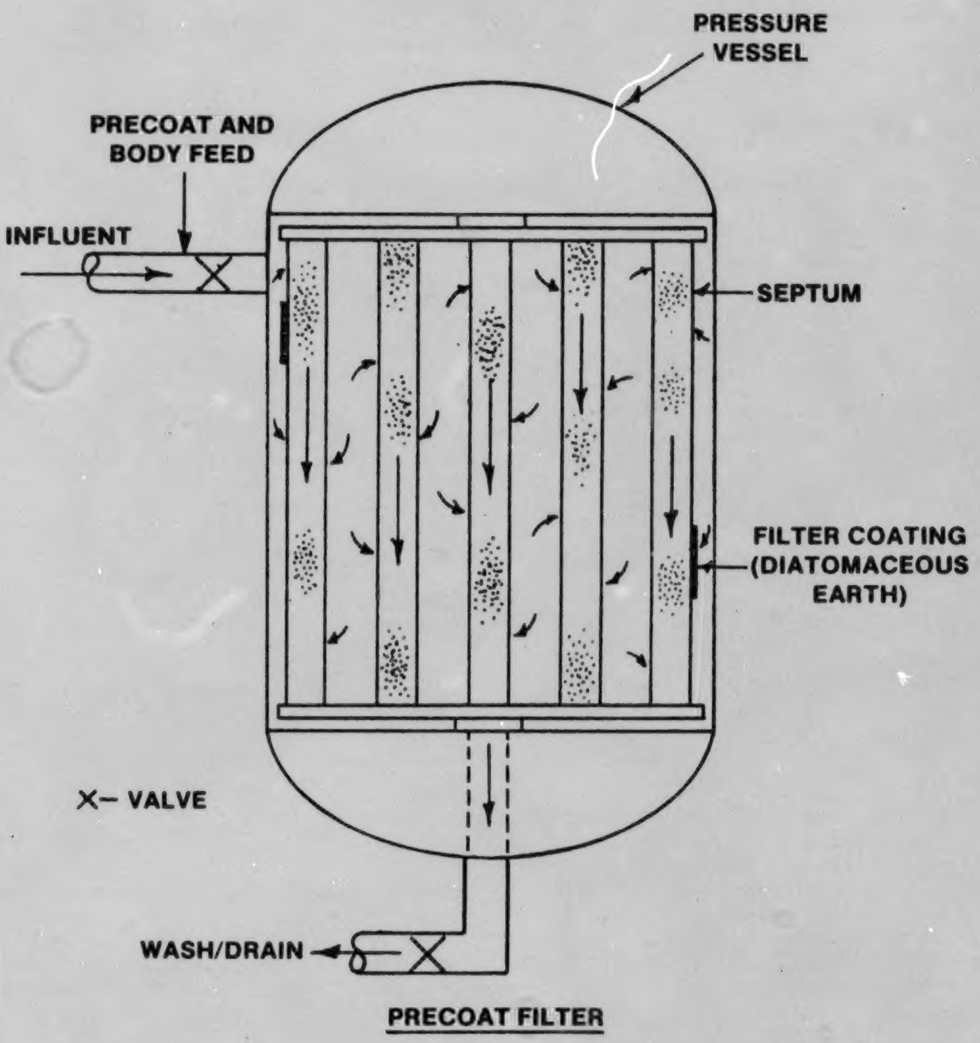

PRESSURE VESSEL
PRECOAT AND BODY FEED
INFLUENT
SEPTUM
FILTER COATING (DIATOMACEOUS EARTH)
X— VALVE
WASH/DRAIN
PRECOAT FILTER

Fig. 6.5 Diatomaceous earth filter

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 240.

6.2A List the four specific classes of filters.

6.2B What is garnet?

6.2C What material is used for precoat and body-feed operations?

6.3 PROCESS PERFORMANCE CONSIDERATIONS

6.30 Filter Media

Filter media most often selected by designers in gravity filtration consists of sand, anthracite coal, and garnet. However, other inert materials can also be used. Gravel is commonly used to support the filter materials. In the diatomaceous earth filtration process, diatomaceous earth is used due to its high strength (very rigid) and high *PERMEABILITY*.[11]

Desirable filter media characteristics are as follows:

1. Good hydraulic characteristics (permeable),
2. Does not react with substances in the water (inert and easy to clean),
3. Hard and durable,
4. Free of impurities, and
5. Insoluble in water.

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[11] ***Permeability** (PURR-me-uh-BILL-uh-tee). The property of a material or soil that permits considerable movement of water through it when it is saturated.*

The various filter media are usually classified by the following characteristics:

1. Effective size,
2. Uniformity coefficient,
3. Specific gravity, and
4. Hardness.

The *EFFECTIVE SIZE* (E.S.) refers to the size of a sieve opening which permits 10 percent (by weight) of the particles (sand) to pass through. In other words, 90 percent of the particles (by weight) are larger in diameter than this sieve opening.

Effective Size, mm = Diameter of 10% by weight grains, mm

Some operational problems can be improved by proper selection of media size. To make judgments about media selection, two factors are very important:

1. The time required for turbidity to break through the filter bed, and
2. The time required for the filter to reach limiting (terminal) *HEAD LOSS.*[12]

With a properly selected media, these times are about the same.

If the limiting head loss is frequently a problem and turbidity breakthrough rarely occurs, then a larger media size may be considered. If turbidity breakthrough is frequently a problem and limiting head loss is rarely encountered, then a smaller media size may be considered.

If both head loss and turbidity breakthrough are constantly a problem, a deeper filter bed with a larger media size should be considered. You must realize that increasing the media depth is not always possible without modification of the filter box or tank. Adequate clearance must be allowed between the top of the media and the bottom of the wash water troughs. Otherwise, filter media will be carried out over the wash troughs during backwash.

The relationship between turbidity breakthrough and limiting head loss is also strongly affected by optimum chemical treatment. Poor chemical treatment can often result in either early turbidity breakthrough or rapid head loss buildup.

UNIFORMITY COEFFICIENT (U.C.) refers to the ratio of particle diameters (based on sieve sizes) comprising 60 percent and 10 percent of the media weight, respectively. Media with lower uniformity coefficients are composed of more uniform particles, that is particles which are all closer to the same size. For example, if the 60 percent sieve size grain diameter is 1 mm and the 10 percent sieve size grain diameter is 0.5 mm, then uniformity coefficient would be:

$$\text{Uniformity Coefficient} = \frac{\text{Diameter of 60\% by weight grains, mm}}{\text{Diameter of 10\% by weight grains, mm}}$$

$$= \frac{1.0 \text{ mm}}{0.05 \text{ mm}}$$

$$= 2.0$$

Selection of an appropriate media size and uniformity coefficient depends on the source water quality, filter design and anticipated filtration rate. Generally the more uniform the media, the slower the head loss buildup. Media with uniformity coefficients of less than 1.5 are readily available. Media with uniformity coefficients of less than 1.3 are only available at a very high cost. Typical filter media characteristics are given in Table 6.1.

6.31 Operational Criteria

6.310 Filter Layout

In gravity filtration, the filter media is usually contained in concrete (also steel or aluminum) filter modules which are all the same size. However, the size will vary widely in surface area from plant to plant. In general, the minimum number of filter modules is four. This allows for one filter to be out of service and you still have 75 percent capacity available. Typical gravity filter media sections are shown in Figure 6.6.

6.311 Filter Production and Filtration Rate

Filter production (capacity) rates are measures of the amount of water that can be processed through an individual filter module in a given time period. *FILTER PRODUCTION* is measured in units of million gallons per day (MGD). *FILTRATION RATE* (or hydraulic loading) is commonly used to measure flow of water through a filter and has units of gallons per minute per square foot of filter surface area (GPM/sq ft) or liters per second/square meter or millimeters per second (mm/sec).

Filtration rates used in gravity filtration generally range from about 2 to 10 GPM/sq ft (1.36 to 6.79 liter per sec/sq m or 1.36 to 6.79 mm/sec). The higher filtration rates are found in plants with dual-media filters. In larger sized water treatment plants, filter capacities range from about 5 to 20 MGD (0.2 to 0.8 cu m/sec), for each filter unit.

6.312 Filtration Efficiency

In the filtration process, filter efficiency is roughly measured by overall plant reduction in turbidity. Reductions of over 99.5 percent can be achieved under optimum conditions, while a poorly operated filter and inadequate pretreatment (coagulation, flocculation, and sedimentation) can result in turbidity removals of less than 50 percent. *THE BEST WAY TO ASSURE HIGH FILTRATION EFFICIENCY IS TO SELECT AN EFFLUENT TURBIDITY GOAL (LEVEL) AND STAY BELOW THE TARGET VALUE (SUCH AS 0.1 TU).*

TABLE 6.1 TYPICAL FILTER MEDIA CHARACTERISTICS[a]

MATERIAL	SIZE RANGE (mm)	SPECIFIC GRAVITY	HARDNESS (MOH scale)
Conventional Sand	0.5 - 0.6	2.6	7
Coarse Sand	0.7 - 3.0	2.6	7
Anthracite Coal	1.0 - 3.0	1.5 - 1.8	3
Garnet	0.2 - 0.4	3.1 - 4.3	6.5 - 7.5
Gravel	1.0 - 50	2.6	7

[a] Adapted from:

1. Stone, B. G. Notes from "Design of Water Treatment Systems," CE 610, Loyola Marymount University, Los Angeles, CA, 1977.
2. *WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES,* by AWWA, 1971.

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[12] *Head Loss. The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as a result of friction losses.*

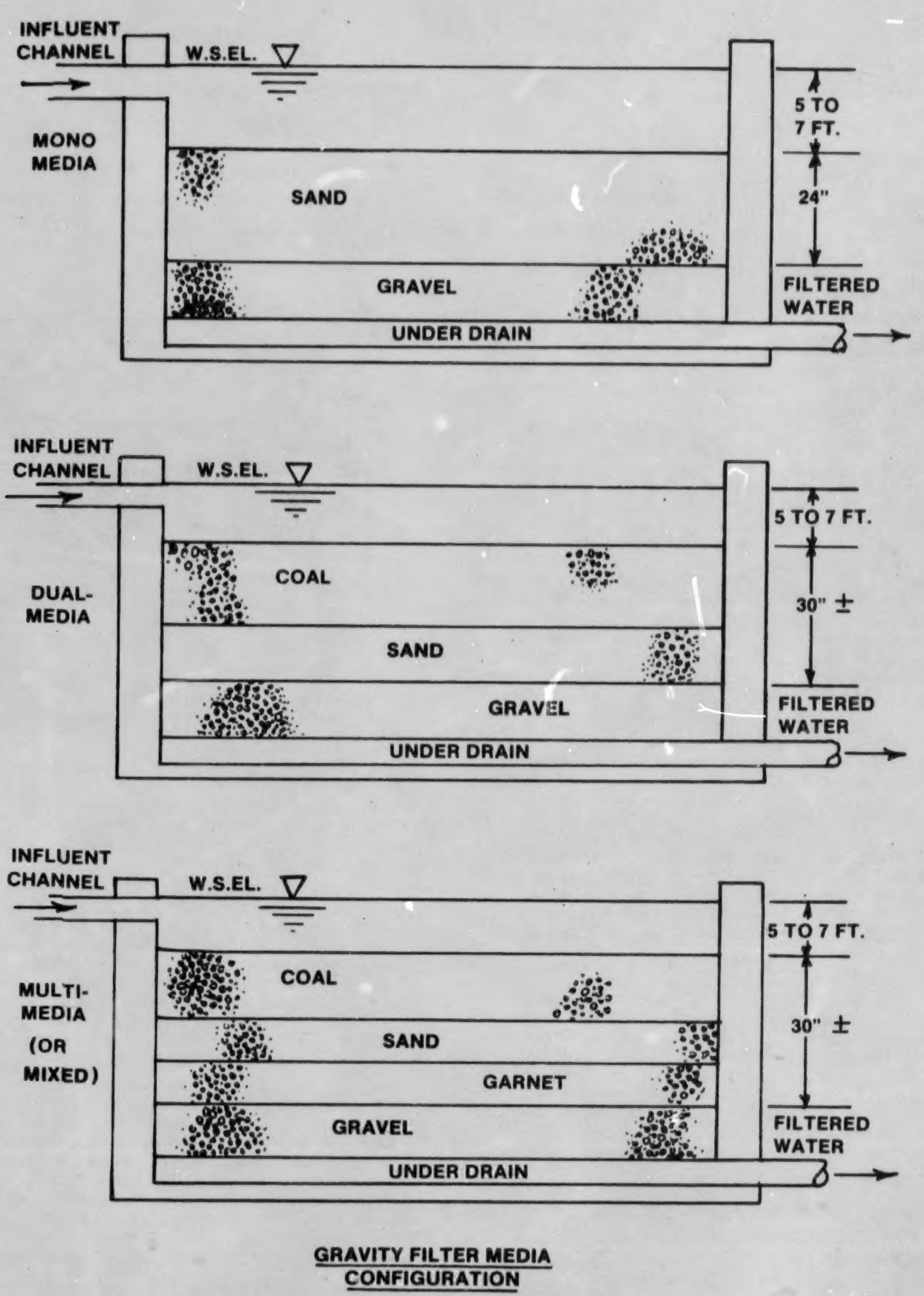

INFLUENT CHANNEL
W.S.EL.
5 TO 7 FT.
MONO MEDIA
SAND
24"
GRAVEL
FILTERED WATER
UNDER DRAIN
INFLUENT CHANNEL
W.S.EL.
5 TO 7 FT.
DUAL-MEDIA
COAL
30" ±
SAND
GRAVEL
FILTERED WATER
UNDER DRAIN
INFLUENT CHANNEL
W.S.EL.
5 TO 7 FT.
MULTI-MEDIA (OR MIXED)
COAL
30" ±
SAND
GARNET
GRAVEL
FILTERED WATER
UNDER DRAIN
GRAVITY FILTER MEDIA CONFIGURATION

Fig. 6.6 Gravity filter media layouts

Filter removal efficiency depends largely on the quality of the water being treated, the effectiveness of the pretreatment processes in conditioning the suspended particles for removal by sedimentation and filtration, and filter operation itself.

Filter unit design and filter media type and thickness also play a role in determining filter removal efficiency, but are less important than water quality and pretreatment considerations. Gravity sand filters usually produce a filtered water turbidity comparable to that of a dual-media filter if the applied water quality is similar. However, the operational differences between sand and dual-media filters are significant. Because of their smaller media grain size (say 0.5 mm), sand filters tend to clog with suspended matter and floc more quickly than dual-media filters. This means frequent backwashing will be required to keep the sand filter operating efficiently. Sand filters have fine, light grains on the top which stop all floc and particulates at the surface of the filter. Dual-media filters have lighter, larger diameter grains in the top layer of the media which stop the larger particles. The smaller particles are usually stopped farther down in the filter. The larger grain size of the anthracite coal layer (up to 1.5 mm) in the top portion of a dual-media filter permits greater depth penetration of solids into the anthracite coal layer and larger solids storage volume in the filter. The sand layer below the anthracite is used as a protective barrier against breakthrough. Chemical dosages are adjusted to keep the solids in the anthracite. Taps at various depths in the filter are used to observe the depth of solids penetration. These characteristics generally produce filter runs which are several times longer and higher filtration rates than those achieved by sand filters. Accordingly, dual-media filters are referred to as "depth filters" while sand filters are known as "surface filters."

Multi-media filters (sand, coal, and garnet) are also used to extend filter run times, and these filters generally perform in a manner similar to gravity sand filters, except that the filter media is enclosed in a pressure vessel. You can get consistently satisfactory filtered water quality with pressure filters if you are careful about the routine operation of this type of filtration system. With the filter media fully enclosed, it is very difficult to assess the media condition by simple visual observation. In addition, excessive pressure in the vessel will force solids as well as water through the filter media. Obviously, this will result in the deterioration of filtered water quality.

In contrast to gravity filtration, diatomaceous earth filtration is essentially a straining process. In many instances, high particulate removal efficiences can be achieved in diatomaceous earth filtration without any preconditioning processes (coagulation, flocculation, and sedimentation). However, the application of diatomaceous earth filtration in larger water treatment plants is limited by the following considerations:

1. High head losses across the filter,
2. Possible sludge disposal problems, and
3. Potential decreased reliability (in terms of quality of filtered water).

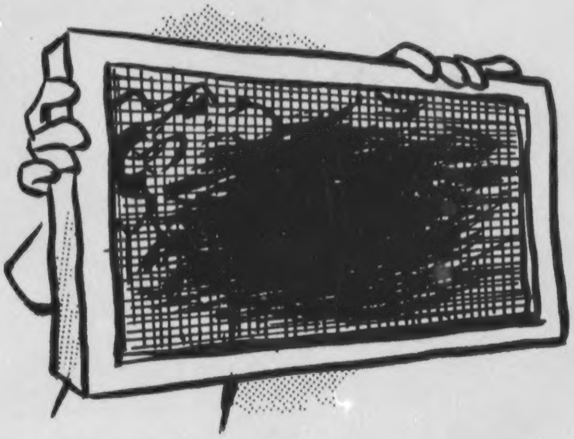
QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 240.

6.3A What material is most often used to support granular filter materials?

6.3B Filtration rate is commonly expressed in what units?

6.3C What is the major operational difference between sand and dual-media filters?



6.32 Filter Operation

6.320 Filtration Mode

In the filtration mode of operation, water containing suspended solids is applied to the surface of the filter media. Depending on the amount of suspended solids in the water being treated and the filtration rate, the filter will exhibit high head loss or "clog" after a given time period (varies from several hours to several days).

CLOGGING may be defined as a buildup of head loss (pressure-drop) across the filter media until it reaches some predetermined design limit. Total design head loss in gravity filters generally ranges from about 6 to 10 feet (1.8 to 3.0 m), depending mainly on the depth of the water over the media. Clogging of the filter leads to *BREAKTHROUGH,*[13] a condition in which solids are no longer removed by the already overloaded filter. The solids pass into the filter effluent where they appear as increased turbidity.

A filter is usually operated until just before clogging or breakthrough occurs, or a specified time period has passed, generally within 72 hours. In order to save money, energy and water by maximizing production before backwashing, some operators run their filters until clogging or breakthrough occurs. This is a poor practice. You must realize that when breakthrough occurs, there will be an increase in filtered water turbidity. See Section 6.91 for detailed procedures on how to check out, start up and shut down filters.

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[13] ***Breakthrough.*** ***A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter effluent turbidity. A breakthrough can occur (1) when a filter is first placed in service, (2) when the effluent valve suddenly opens or closes, and (3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).***

6.321 Backwashing

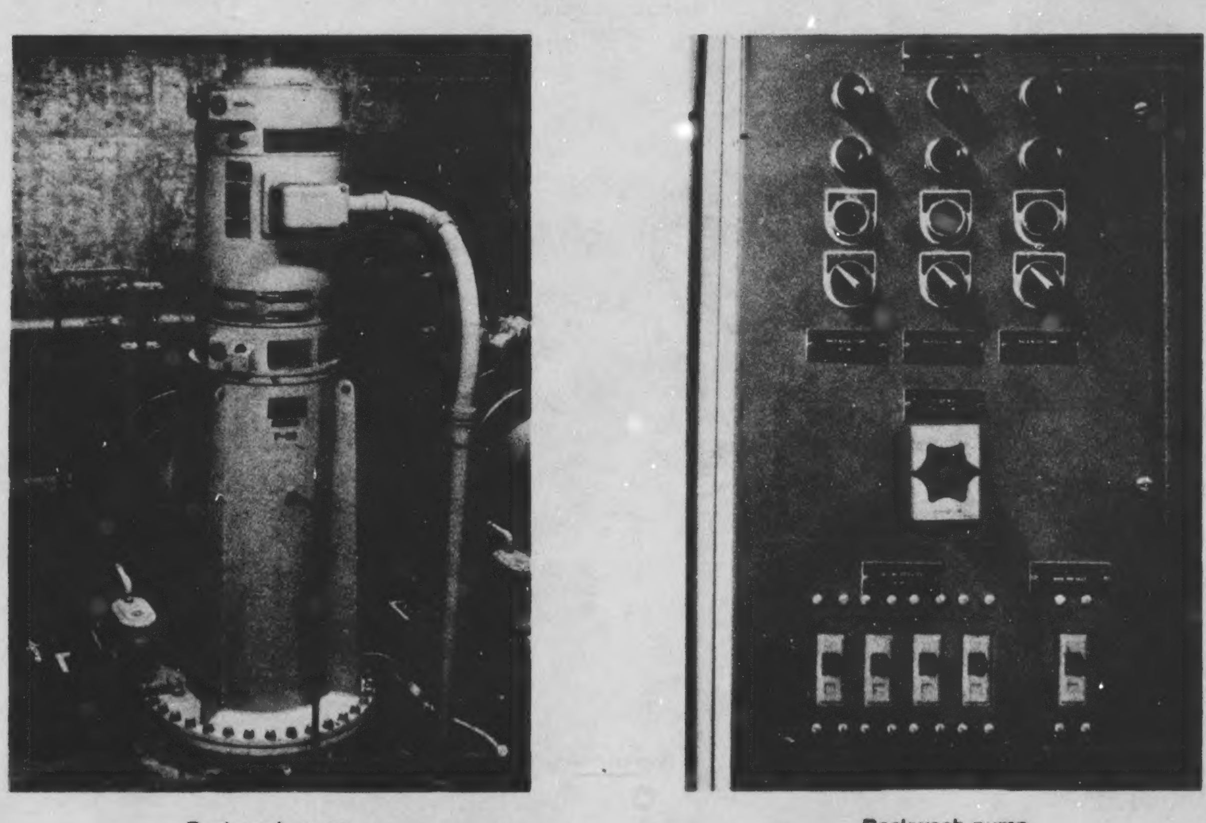
After a filter clogs (reaches maximum head loss), or breakthrough occurs, or a specified time period has passed, the filtration process is stopped and the filter is taken out of service for cleaning or "backwashing." *BACKWASHING* is the process of reversing the flow of water through the filter media to remove the entrapped solids. In order to remove the trapped solids from the filter media in the gravity and pressure filtration processes, the filter media must be expanded or *FLUIDIZED*[14] by reversing the flow of water. Backwash flow rates ranging from 10 to 25 GPM/sq ft (6.8 to 17 liters per sec/sq m or 6.8 to 17 mm/sec) of filter media surface area are usually required to clean the filter adequately. Insufficient backwash rates may not completely remove trapped solids from the filter media, while too high a backwash rate may cause excessive loss of filter media and media disturbance (mounding). Usually higher backwash rates are required at high temperatures and with larger media. Backwashing at too high a rate is much more destructive than at too low a backwash rate. See Section 6.911, "Backwash Procedures," for details on how to backwash filters.

In diatomaceous earth filtration, accumulated solids are also removed by reversing the flow through the filter. However, the diatomaceous earth filter coating itself must also be removed; this contributes greatly to the volume of waste sludge produced by this filtration process. An advantage is that less water is required for backwashing.

The pressurized water supply required for backwashing a filter is usually supplied by a backwash pump which uses filtered water as a supply source. In order to provide enough water storage for backwashing one or more filters, an elevated storage tank can be used to store enough water to backwash large filters and multiple filters. A typical backwash pump and control panel are shown in Figure 6.7.

The backwashing process may use about two to four percent of the process water for transporting the wash water to dewatering and final solids disposal processes (see Chapter 17, "Handling and Disposal of Process Wastes"). If the wash water can be removed from the water surface in the solids disposal process, a major portion of the water can be recycled through the water treatment plant. In some plants the wash water is recycled directly to the headworks (ahead of flash mixer).

Wash water troughs are installed in gravity filters to aid in collecting wash water from the filters (see Figures 6.8 and 6.9).



Backwash pump

Backwash pump
control panel

Fig. 6.7 Backwash pumping

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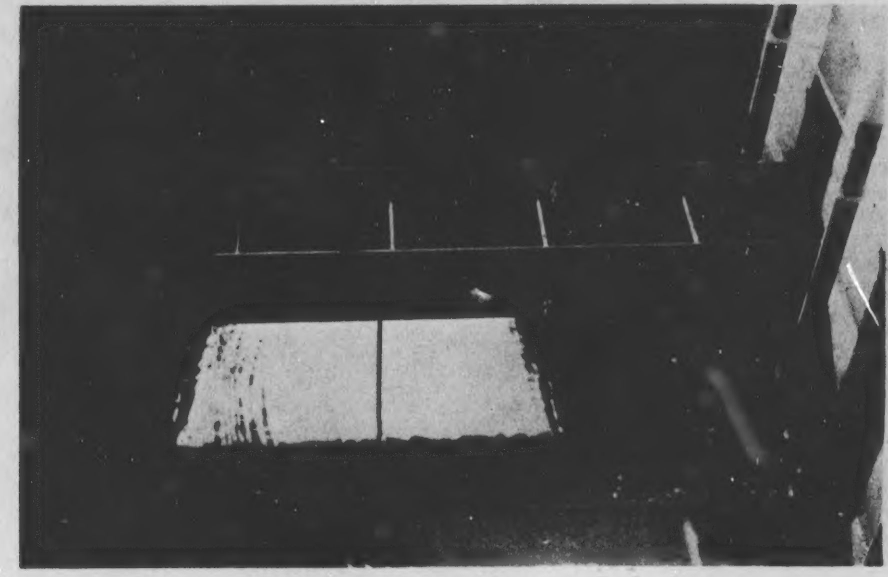
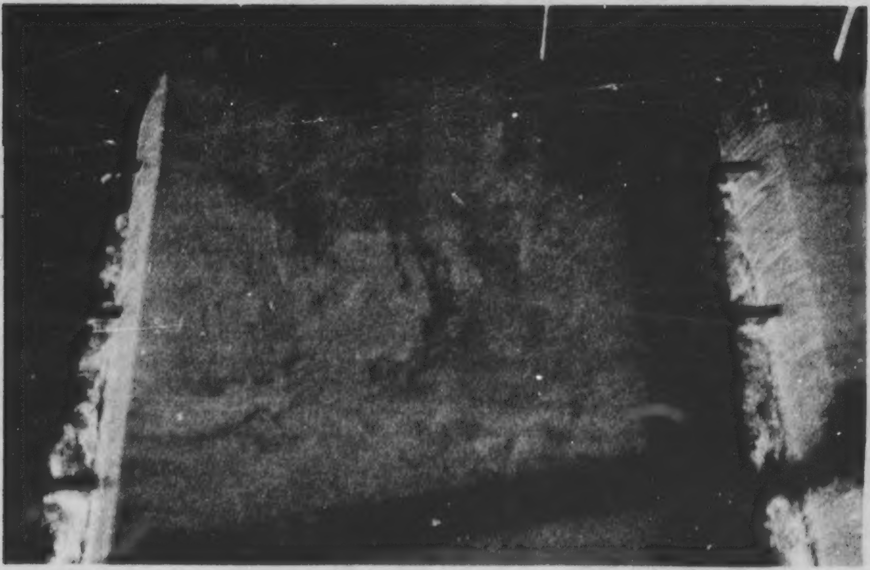
[14] *Fluidized (FLEW-id-I-zd). A mass of particles that is made to flow like a liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by backwashing water through the filter.*



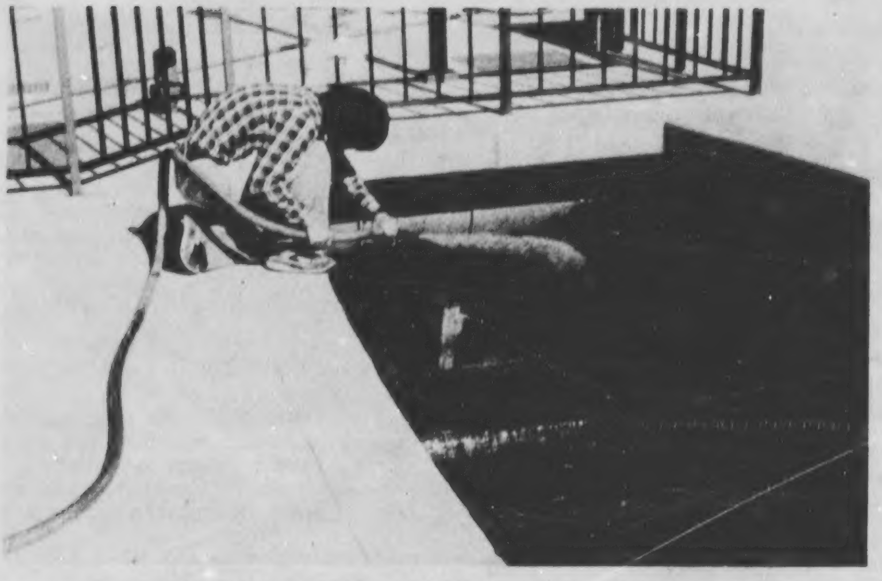
Washwater trough
(Filter water-surface level drawn down prior to backwash)

Filter during backwash mode

Fig. 6.8 Backwashing



Removal of solids during backwash



Operator hosing down filter sidewalls during backwash
(NOTE: Operator is too close to edge and
could fall in — should be behind guardrails)

Fig. 6.9 Backwashing

6.322 Surface Wash

In order to produce optimum cleaning of the filter media during backwashing and to prevent mud balls, surface wash (supplemental scouring) is usually required. Surface wash systems provide additional scrubbing action to remove attached floc and other entrapped solids from the filter media. Four types of surface wash systems (Figure 6.10) are:

1. Baylis,
2. Fixed grid,
3. Rotary, and
4. Air scour.

FIXED GRID
ROTARY
BAYLIS
AIR SCOUR

The first three surface wash systems are mechanical or water-powered, while the fourth system uses air to create the washing action.

6.33 Filter Control Systems

Filter control systems regulate flow rates through the filter by maintaining an adequate head above the media surface (see Figures 6.11 and 6.12). This head (*SUBMERGENCE*[15]) forces water through a gravity filter.

A filter control system also prevents sudden flow increases or surges which could discharge solids trapped on the filter media. If the solids were suddenly dislodged, they would seriously degrade water quality. One way to prevent incoming water from disturbing (scouring) the media is to maintain an adequate depth of water above the media surface. In this way, the force of the incoming water is absorbed before it reaches the media, thus preventing scouring.

Filter control systems commonly used in gravity filtration installations include the following:

1. Rate-of-flow,
2. Split flow,
3. Declining rate, and
4. Self backwash.

In *RATE-OF-FLOW* control systems, each filter influent control valve is connected to a flow meter. As the filter run continues and the media begins to clog, the control valve slowly opens to maintain a constant flow of water through the filter. A master controller is required to monitor the overall plant flow and adjust the flow rate of each filter accordingly. With this system, all filters operate at the same flow rate, but the rate is variable, dropping each time a new filter is backwashed.

In the *SPLIT-FLOW* control system, the flow to each filter influent is "split" or divided by a weir. With this system equal flow is automatically distributed to each filter. The filter effluent valve position is controlled by the water level in the filter. Each filter operates within a narrow water level range.

In *DECLINING-RATE* filters, flow rate varies with head loss. Each filter operates at the same, but variable, water surface level. This system is relatively simple, but requires an effluent control structure (weir) to provide adequate media submergence. Effluent control structures are usually desirable with the other systems described here as well.

In the *SELF-BACKWASH* (or Streicher design) system, influent flow to each filter is divided by a weir. The water surface level in each filter varies according to head loss, but the flow rate remains constant for each filter. This system reduces the amount of mechanical equipment required for operation and backwashing, such as washwater pumps, and also requires an effluent control structure and a deeper filter box.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 241.

6.3D What two main factors influence the time period before a filter becomes clogged?

6.3E Under what conditions is the filtration process stopped and the filter taken out of service for cleaning or "backwashing?"

6.3F List four types of surface wash (supplemental scour) systems for filters.

6.3G What aspects of the filtration process are actually controlled by the filter control system?

6.4 ACTIVATED CARBON FILTERS

The primary purpose of filtration is to remove suspended particles and floc from the water being treated. Another dimension is added to the filtration process by the use of activated carbon (granular form) as a filter media. The high adsorptive capacity of activated carbon enables it to remove taste- and odor-causing compounds, as well as other trace organics from the water. However, not all organic compounds are removed with the same degree of efficiency.

While activated carbon filtration is very effective in removing taste- and odor-causing compounds, the construction, carbon handling equipment and operating costs are generally quite high. Still, activated carbon can be added to existing filter beds or can be incorporated as a separate process. Provisions must be made for regeneration or reactivation of "spent" carbon (carbon which has lost its adsorptive capacity). Usually arrangements are made with the carbon manufacturer to regenerate or exchange spent carbon.

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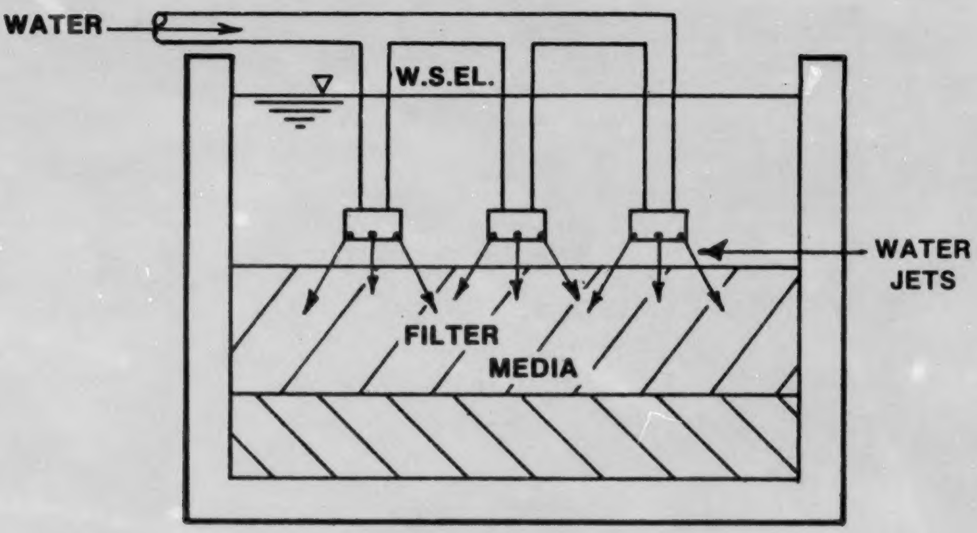
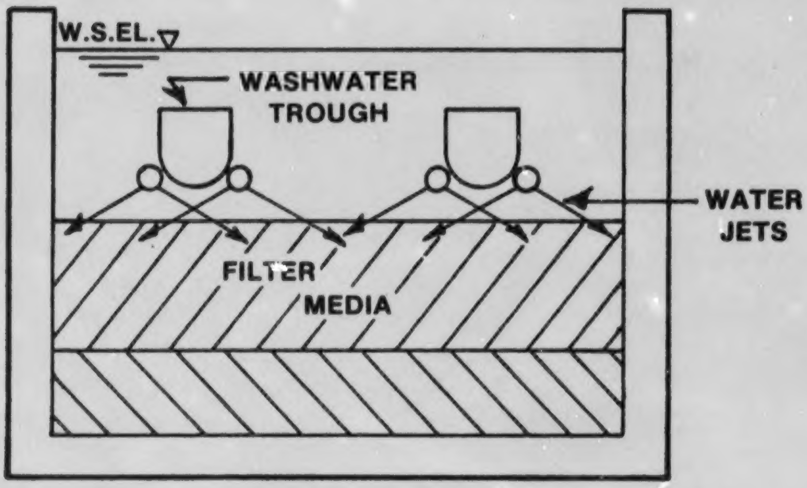
[15] *Submergence. The distance between the water surface and the media surface in a filter.*


WATER
W.S.EL.
WATER JETS
FILTER MEDIA

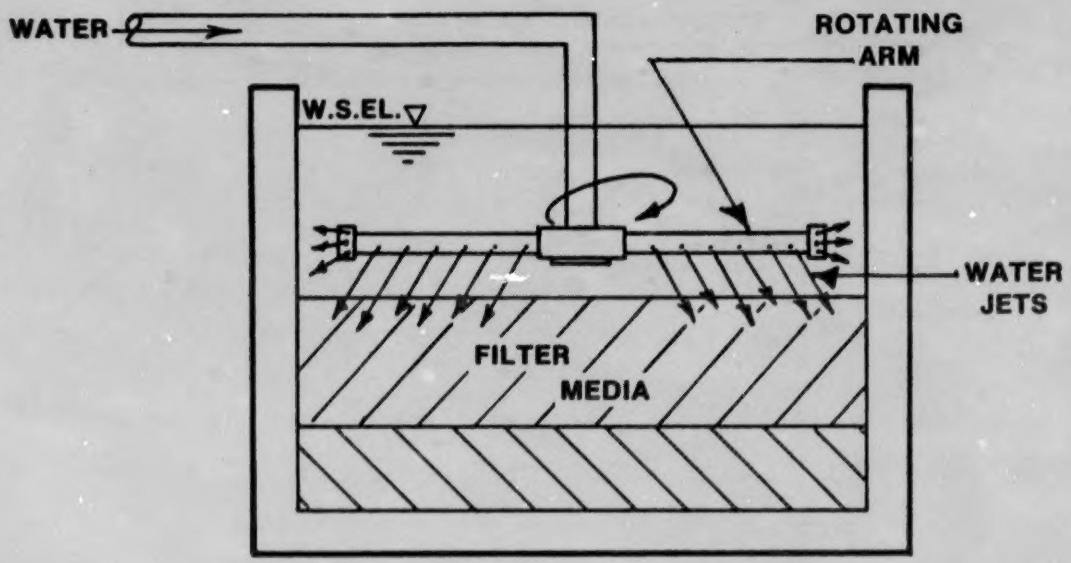
BAYLIS SURFACE WASH


W.S.EL.
WASHWATER TROUGH
WATER JETS
FILTER MEDIA

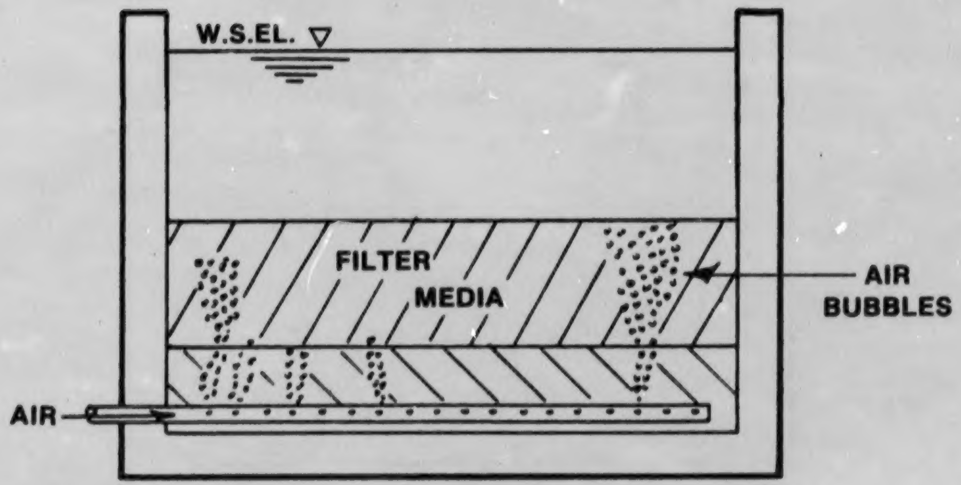
FIXED GRID SURFACE WASH

SUPPLEMENTAL SCOUR SYSTEMS

Fig. 6.10 Surface wash systems


WATER
ROTATING ARM
W.S.EL.
WATER JETS
FILTER MEDIA

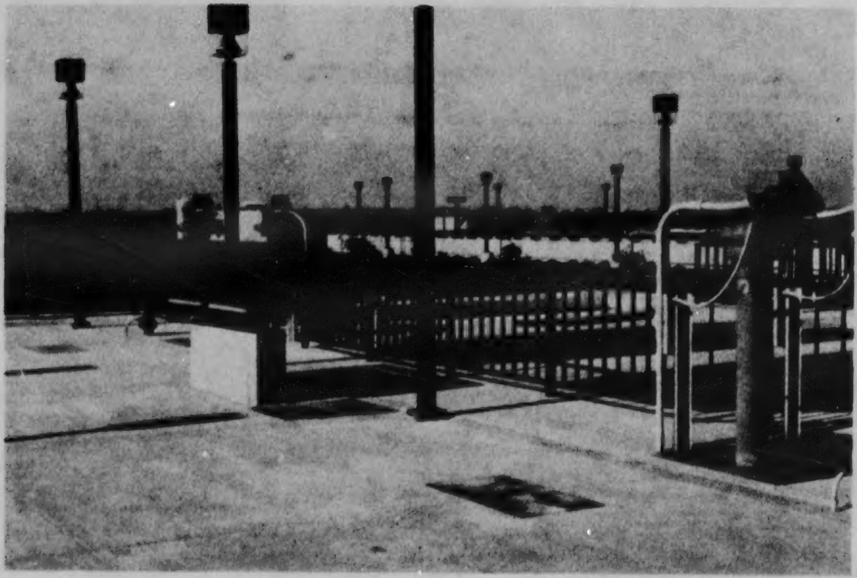
ROTARY SURFACE WASH


W.S.EL.
FILTER MEDIA
AIR BUBBLES
AIR

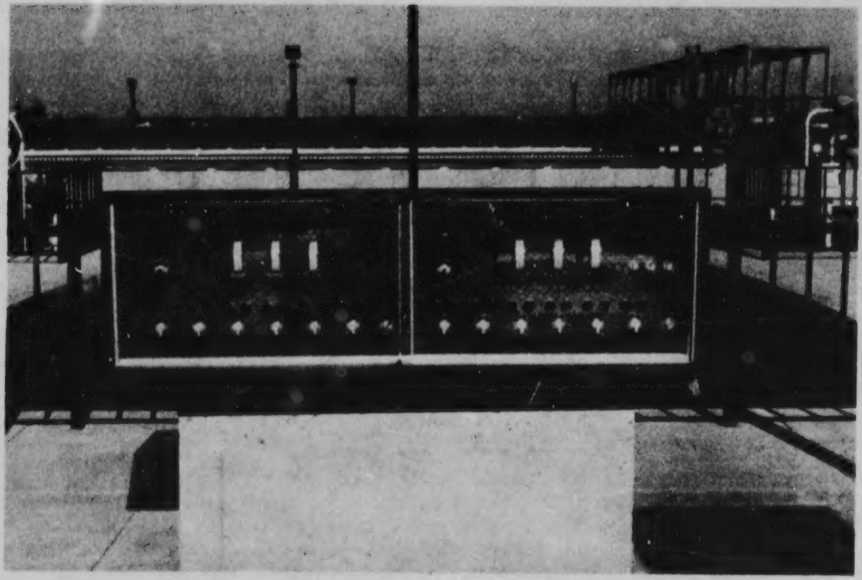
AIR WASH

SUPPLEMENTAL SCOUR SYSTEMS

Fig. 6.10 Surface wash systems (continued)

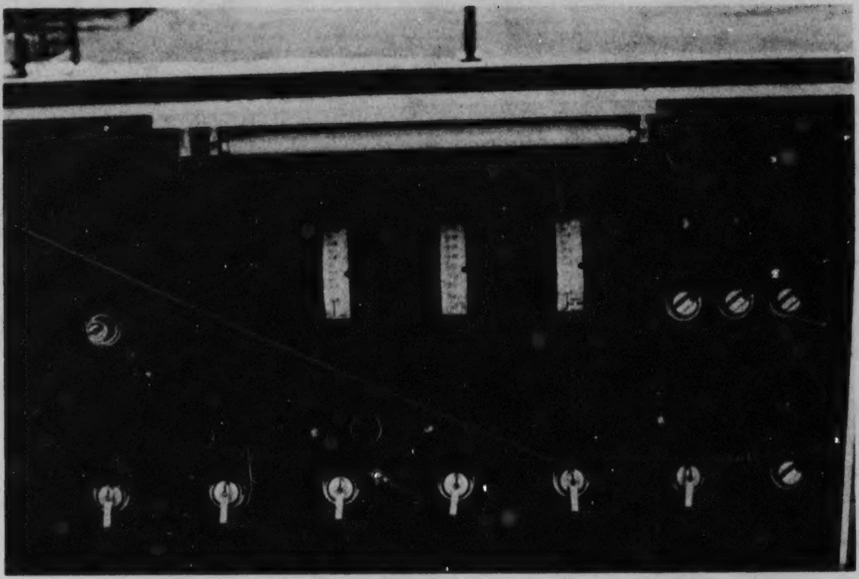


Filter operating deck

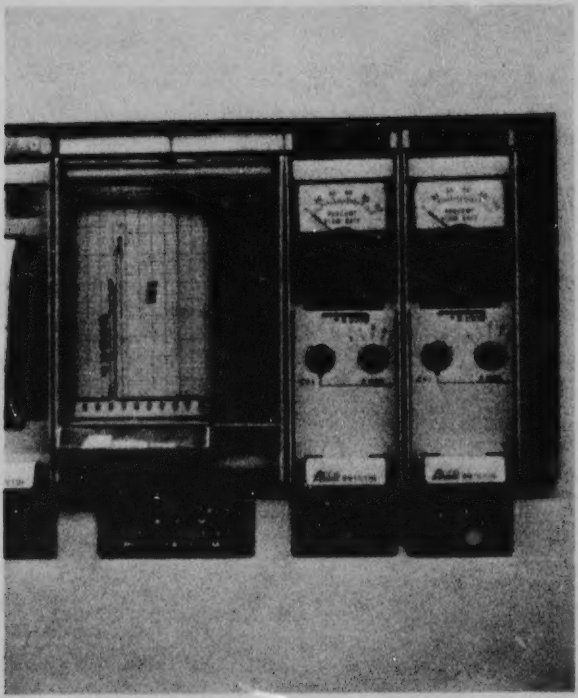


Filter control panels for two filters

Fig. 6.11 Filter controls



Filter control panel



Filter instrumentation
(Backwash rate, backwash and surface wash water consumption)

Fig. 6.12 Filter controls

An alternative to activated carbon filtration for reducing taste and odor levels is the use of powdered activated carbon prior to sedimentation and filtration. This option is usually more cost effective than activated carbon filtration, but generally will not yield equivalent results, due to operational and physical problems which limit the amount of powdered activated carbon that can be applied to the water being treated. Powdered activated carbon is difficult to handle due to dust problems.

6.5 INTERACTION WITH OTHER TREATMENT PROCESSES

6.50 Importance of Pretreatment

The purpose of filtration is the removal of particulate impurities and floc from the water being treated. In this regard, the filtration process is the final step in the solids removal process which usually includes the pretreatment processes of coagulation, flocculation, and sedimentation.

The degree of pretreatment applied prior to filtration depends on the type of treatment plant (pressure filter, diatomaceous earth filtration, or gravity filtration) and the size of the treatment facility. Most large municipal treatment plants include complete pretreatment facilities and gravity filtration. In any event, the importance of pretreatment prior to filtration can not be overemphasized.

Floc particles which are carried over into the filter influent must be small enough to penetrate the upper filter media (depth filtration). Floc which is too large will cause the top portion of the filter bed to clog rapidly, thus leading to short filter runs. In addition, large floc (particularly alum floc) is often weak and easily broken up by water turbulence. This can cause degradation of effluent water quality.

Ideally, floc removal is accomplished by contact with the media grains (sand, coal, and garnet) throughout the upper depths of the filter. After the initial coating or conditioning of the media surfaces with floc at the beginning of the filtration cycle, subsequent applications of floc will build upon the material previously deposited on the media surface. This process is often referred to as the "ripening period." Higher filter effluent turbidities may occur during the first few minutes at the beginning of the filter run until the "ripening period" is completed.

At filtration rates below 4 GPM/sq ft (2.72 liters per sec/sq m or 2.72 mm/sec) alum or iron coagulants usually give adequate treatment without assistance.

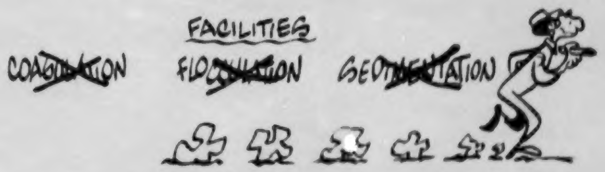
At filtration rates above 4 or 5 GPM/sq ft (2.72 or 3.40 liters per sec/sq m or 2.72 or 3.40 mm/sec) iron and alum floc will shear in the pores of the filter and short filter runs will result because of turbidity breakthrough. Under these conditions the addition of a polymer coagulant aid or a chemical filter aid is often beneficial.

The polymers most frequently found to be successful in this application are moderate molecular weight cationic polymers (DADMA) and relatively high molecular weight nonionic polymers (polyacrylamides). The cationic polymers are best added ahead of the flocculation process to strengthen the floc formed. The nonionic polymers are generally added in the settled water as it moves towards the filters from the sedimentation basins.

Typical doses for cationic polymers range from 0.25 to 2 mg/*L*. Typical doses for nonionic polyers range from 0.02 to 0.2 mg/*L*.

6.51 In-Line Filtration

IN-LINE FILTRATION refers to the addition of coagulant chemicals immediately before the water enters the filtration system (Figure 6.13). This pretreatment method is commonly used in pressure filter installations. Chemical filter aids are added directly to the filter inlet pipe and are mixed by the flowing water. When this is done, separate flocculation and sedimentation facilities are eliminated.



This process is not as efficient in forming floc as conventional or direct filtration when source water quality has variable turbidity and bacterial levels. Problems may develop with the formation of floc in the water after filtration.

6.52 Conventional Filtration (Treatment)

The conventional filtration (treatment) process is used in most municipal treatment plants in the United States. This process includes "complete" pretreatment (coagulation, flocculation, and sedimentation) as shown in Figure 6.13. This system provides a great amount of flexibility and reliability in plant operation, especially when source water quality is highly variable or is high in suspended solids.

A chemical application point just prior to filtration permits the application of a filter-aid chemical (such as a nonionic polymer) to assist in the solids-removal process, especially during periods of pretreatment process upset, or when operating at high filtration rates.

6.53 Direct Filtration

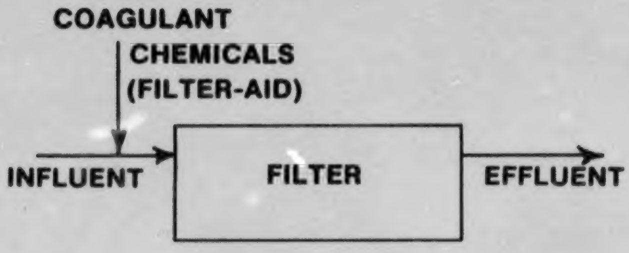
Direct filtration is considered a feasible alternative to conventional filtration, particularly when source waters are low in turbidity, color, plankton, and coliform organisms. Direct filtration can be defined as a treatment system in which filtration is not preceded by sedimentation, as shown in Figure 6.13. Many direct filtration plants provide rapid mix, short detention without agitation (30 to 60 minutes) followed by filtration. As in conventional filtration, a chemical application point just prior to filtration permits the addition of a filter-aid chemical.

6.6 PROCESS CONTROL

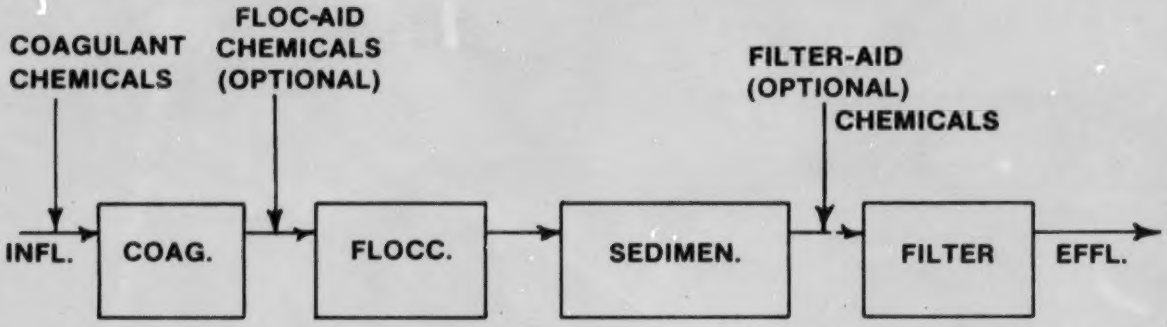
In theory, the physical and chemical processes governing solids removal in filtration are rather complex. Yet, from a practical perspective, the treatment plant operator must be provided with the means to measure and control the performance of the filtration process on a day-to-day basis. In this regard, filter influent water quality (turbidity), filter performance (head loss buildup rate and filter run time), and filter effluent water quality (turbidity) are important process control guidelines.

An efficient means of handling washwaters is to recycle the water to the beginning of the plant (before the flash mixer).

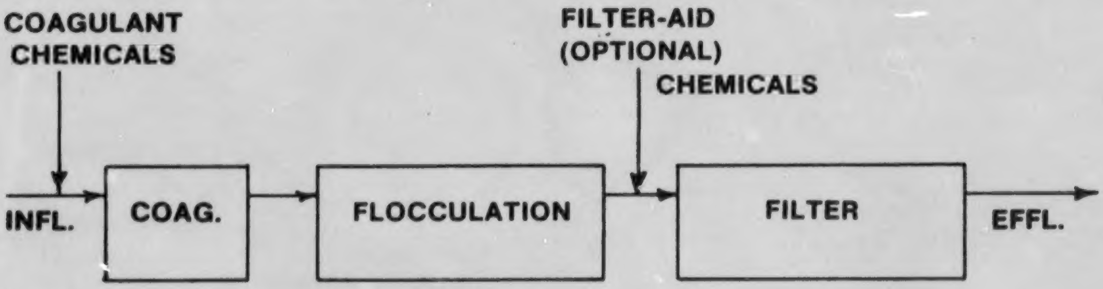
Means for measuring and controlling the filtration process are described in the following sections.


COAGULANT
CHEMICALS
(FILTER-AID)
INFLUENT
FILTER
EFFLUENT

IN-LINE FILTRATION


COAGULANT
CHEMICALS
FLOC-AID
CHEMICALS
(OPTIONAL)
FILTER-AID
(OPTIONAL)
CHEMICALS
INFL.
COAG.
FLOCC.
SEDIMEN.
FILTER
EFFL.

CONVENTIONAL FILTRATION


COAGULANT
CHEMICALS
FILTER-AID
(OPTIONAL)
CHEMICALS
INFL.
COAG.
FLOCCULATION
FILTER
EFFL.

DIRECT FILTRATION

Fig. 6.13 Filtration systems

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 241.

6.4A What is the primary purpose of using activated carbon (granular form) as a filter media?

6.5A What is "in-line filtration?"

6.5B When and where are filter-aid chemicals used?

6.5C When is direct filtration used?

6.6A What factors must an operator measure to control the performance of the filtration process on a day-to-day basis?

End of Lesson 1 of 2 Lessons
on
FILTRATION

DISCUSSION AND REVIEW QUESTIONS

Chapter 6. FILTRATION

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. What is the primary purpose of the filtration process?
2. Why is diatomaceous earth filtration used in some water treatment applications and not in others?
3. What are the desirable characteristics for filter media?
4. If both head loss and turbidity breakthrough are constantly a problem due to improperly sized media, what should be done?
5. What problems can develop if backwash rates are either too high or too low?

Chapter 6. FILTRATION

(Lesson 2 of 2 Lessons)

6.7 OPERATING PROCEDURES ASSOCIATED WITH NORMAL PROCESS CONDITIONS

6.70 Indicators of Normal Operating Conditions

Filtration is the final and most important step in the solids removal process. From a water quality standpoint, filter effluent turbidity will give you a good indication of overall process performance. However, you must also monitor the performance of each of the preceding treatment processes (coagulation, flocculation, and sedimentation) as well as filter effluent water quality, in order to anticipate water quality or process performance changes which might affect filter operation.

In the normal operation of the filtration process, the operator should closely monitor filter influent turbidity as well as filter effluent turbidity levels with a *TURBIDIMETER*[16] (Figure 5.14). Filter influent turbidity levels (settled turbidity) can be checked on a periodic basis (say once every two hours) by securing a grab sample either at the filter or from the laboratory sample tap (if such facilities are provided). However, filter effluent turbidity is best monitored and recorded on a continuous basis by an on-line turbidimeter. If the turbidimeter is provided with an alarm feature, virtually instantaneous response to process failures can be achieved.

Other indicators that can be monitored to determine if the filter is performing normally include head loss buildup and filter effluent color.

A written set of process guidelines should be developed to assist the operator in evaluating normal process conditions and in recognizing abnormal conditions. These guidelines can be developed based on water quality standards, design considerations, water quality conditions, and most importantly, trial and experience.

6.71 Process Actions

In the normal operation of the filtration process, you will perform a variety of functions with emphasis on maintaining a high quality filtered water. For all practical purposes, the quality of the filter effluent constitutes the final product quality that will be distributed to consumers.

Typical functions you will be expected to perform in the normal operation of the filtration process include the following:

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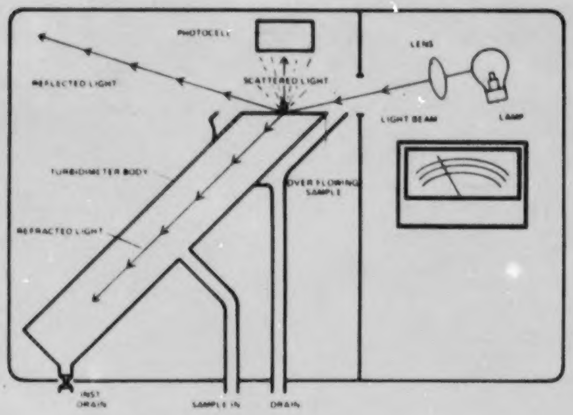
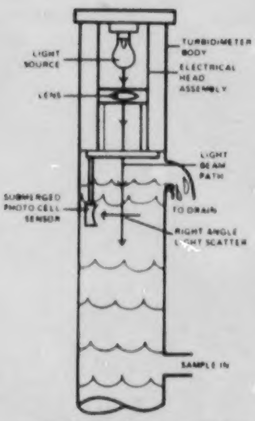
[16] *Turbidimeter. An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.*

FLOW DIAGRAM


PHOTOCELL
LENS
REFLECTED LIGHT
SCATTERED LIGHT
LIGHT BEAM
LAMP
TURBIDIMETER BODY
OVER FLOWING SAMPLE
REFRACTED LIGHT
INST DRAIN
SAMPLE IN
DRAIN

SURFACE SCATTER TURBIDIMETER 5
HACH

Raw Water On-line Turbidimeter


LIGHT SOURCE
TURBIDIMETER BODY
ELECTRICAL HEAD ASSEMBLY
LENS
LIGHT BEAM PATH
SUBMERGED PHOTO CELL SENSOR
TO DRAIN
RIGHT ANGLE LIGHT SCATTER
SAMPLE IN

HOW IT WORKS

Hach's Low Range Turbidimeter is a continuous reading nephelometer. A strong light beam is passed through a water sample and measurement of the amount of light scattered by the turbidity particles is made.

If the turbidity of the sample is negligible, no light reaches the photocell sensor. Conversely, the presence of turbidity in the sample results in light being scattered with the corresponding number of NTUs shown on the master indicator.

The most important advantage of a nephelometer is that a very intense beam of light can be passed through the sample. This results in a very high sensitivity which permits accurate measurements of trace turbidity amounts.

MASTER INDICATOR
INSTRUMENT BODY

Fig. 6.14 Continuous flow filter influent and effluent turbidimeter

(Permission of the Hach Company)

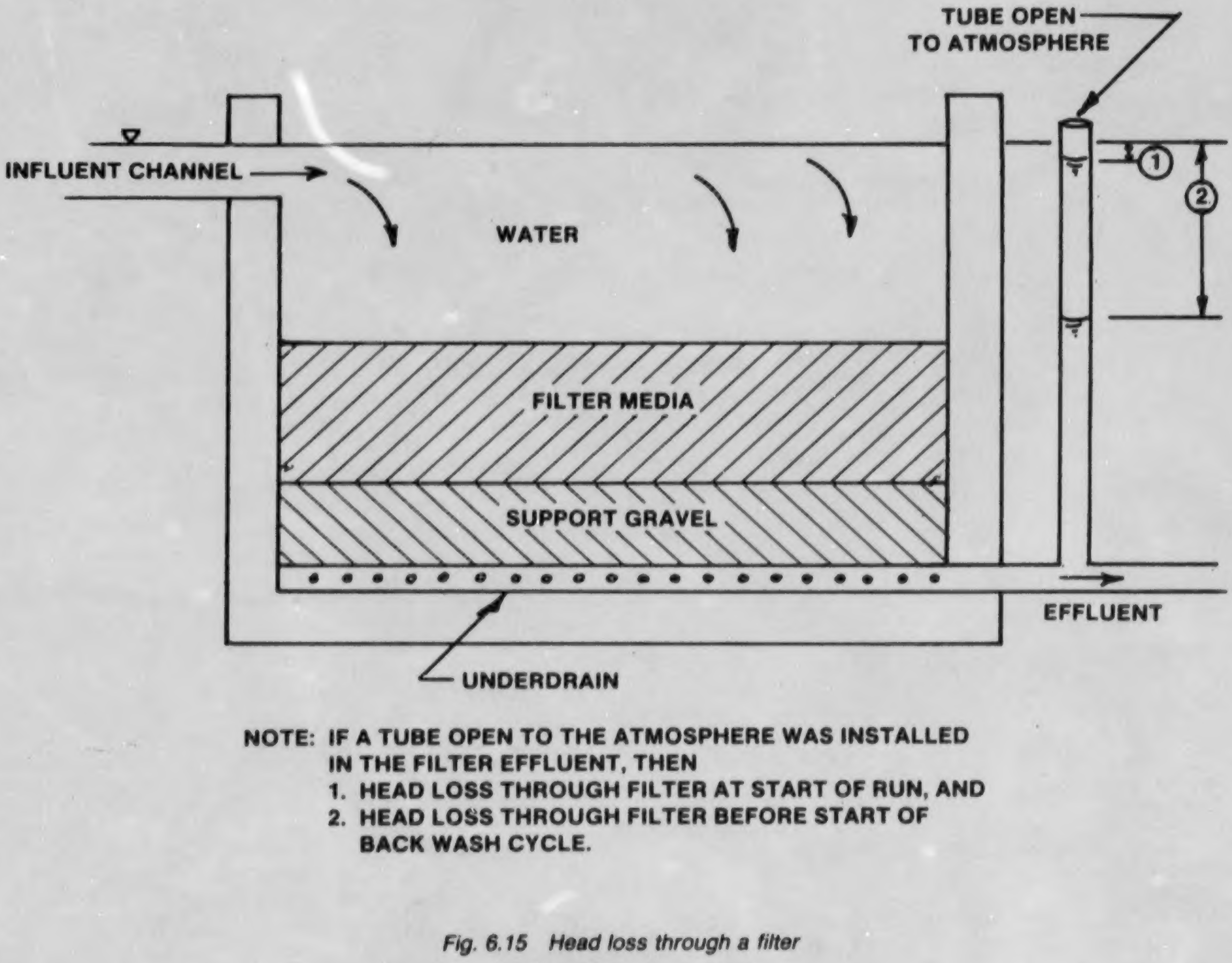
1. Monitor process performance;
2. Evaluate water quality conditions (turbidity) and make appropriate process changes;
3. Check and adjust process equipment (change chemical feed rates);
4. Backwash filters;
5. Evaluate filter media condition (media loss, mud balls, cracking); and
6. Visually inspect facilities.

Monitoring process performance is an on-going activity. You should look for and attempt to anticipate any treatment process changes or other problems that might affect filtered water quality, such as a chemical feed system failure.

Measurement of head loss buildup (Figure 6.15) in the filter media will give you a good indication of how well the solids removal process is performing. The total designed head loss from the filter influent to the effluent in a gravity filter is usually about 10 feet (3 m). The actual head loss from a point above the filter media to a reference point in the effluent can be monitored as "loss-in-head" (or "loss-of-head"). For example, suppose that a gravity filter is designed for a total potential head loss of 10 feet (3 m). At the beginning of the filtration cycle the actual measured head loss due to clean media and other hydraulic losses is 3 feet (0.9 m). This would permit an additional head loss of 7 feet (2.1 m) due to solids accumulation in the filter. In this example, a practical cut-off point might be established at an additional six feet (1.8 m) of head loss (total of nine feet (2.7 m)) for backwashing purposes.

The rate of head loss buildup is also an important indicator of process performance. Sudden increases in head loss might be an indication of surface sealing of the filter media (lack of depth penetration). Early detection of this condition may permit you to make appropriate process changes such as adjustment of the chemical filter-aid feed rate or adjustment of filtration rate.

Monitoring of filter effluent turbidity on a continuous basis with an on-line turbidimeter (Figure 6.14) is highly recommended. This will provide you with continuous feedback on the performance of the filtration process. In most instances it is desirable to cut off (terminate) filter operation at a predetermined effluent turbidity level. Preset the filter cut off control at a point where your experience and tests show break through will soon occur (Figure 6.16).



NOTE: IF A TUBE OPEN TO THE ATMOSPHERE WAS INSTALLED IN THE FILTER EFFLUENT, THEN
1. HEAD LOSS THROUGH FILTER AT START OF RUN, AND
2. HEAD LOSS THROUGH FILTER BEFORE START OF BACK WASH CYCLE.

Fig. 6.15 Head loss through a filter

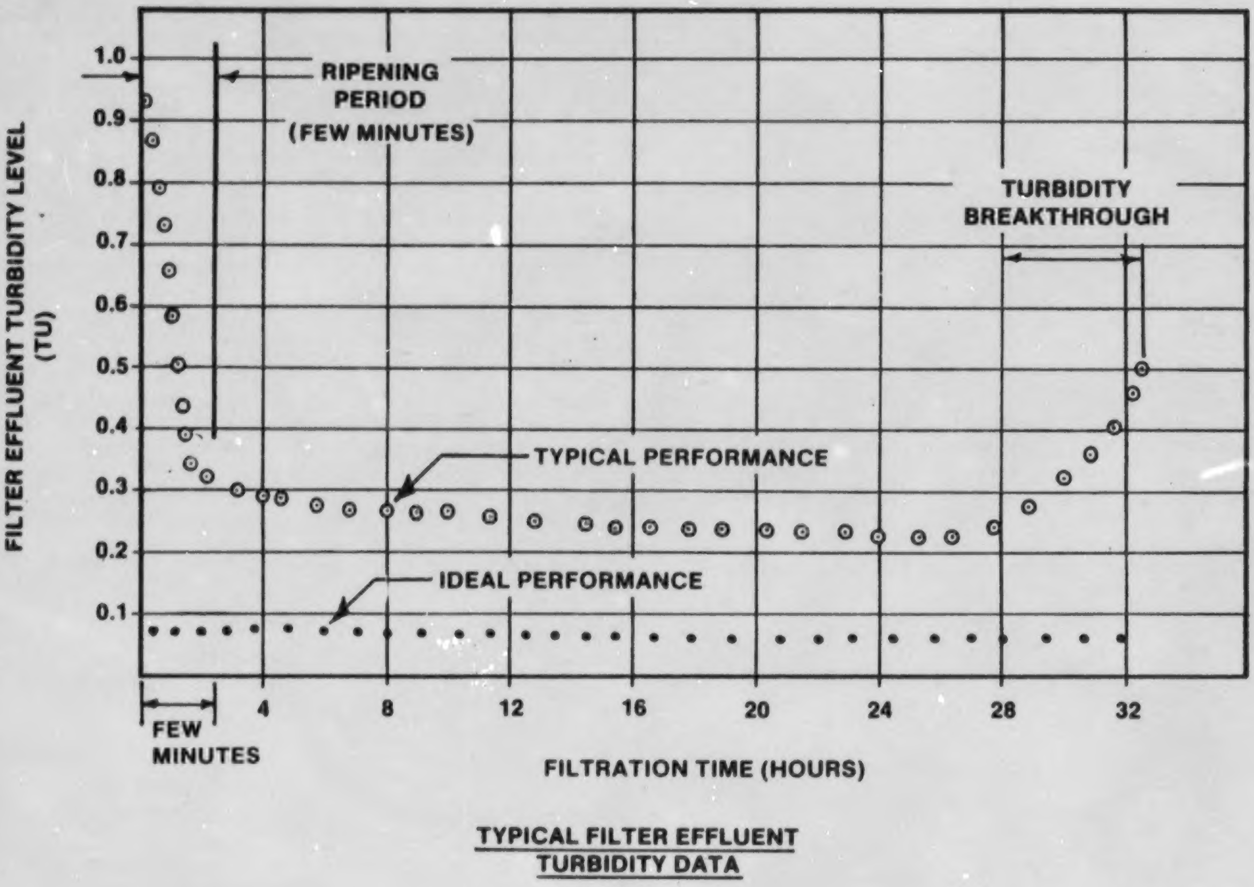


Fig. 6.16 Typical filter effluent turbidity graph

In the normal operation of the filter process, it is best to calculate when the filtration cycle will be completed on the basis of the following guidelines:

1. Head loss,
2. Effluent turibidity level, and
3. Elapsed run time.

A predetermined value is established for each guideline as a cut off point for filter operation. When any one of these levels is reached, the filter is removed from service and backwashed (see Section 6.9, "Starting and Shutdown Procedures," for step-by-step procedures).

Usually plant operators compare filter performance from season to season and from plant to plant by comparing the filter-run length in hours. The reason for this is that as the filter run gets shorter, the amount of water wasted in backwash becomes increasingly important when compared by the amount of water produced during the filter run. Percent backwash water statistics are also occasionally collected.

Although of some use, filter run length is not satisfactory without considering the filtration rate as well. For example, at a filtration rate of 6 GPM/sq ft (4.1 liters per sec/sq m or 4.1 mm/sec), an 18-hour filter run is quite adequate. Whereas, at a filtration rate of 1.5 GPM/sq ft (1.0 liters per sec/sq m or 1.0 mm/sec), an 18-hour filter run is not satisfactory.

The best way to compare filter runs is by using the Unit Filter Run Volume (UFRV) technique. The UFRV is the volume of water produced by the filter during the course of the filter run divided by the surface area of the filter. This is usually expressed in gallons per square foot (liters per square meter). UFRVs of 5,000 gal/sq ft (203,710 liters per square meter) or greater are satisfactory, and UFRVs greater than 10,000 gal/sq ft (407,430 liters per square meter) are desirable. In the examples cited in the previous paragraph, the UFRV for the filter operating at 6 GPM/sq ft (4.1 liters per sec/sq m or 4.1 mm/sec) would be 6,480 gal/sq ft (264,010 liters per sq m), and the filter operating at 1.5 GPM/sq ft (1.0 liters per sec/sq m or 1.0 mm/sec) would be 1,620 gal/sq ft (66,000 liters per sq m).

Water quality indicators used to assess process performance include turbidity and color (Figure 6.17). Based on an assessment of overall process performance, you may need to make changes in the coagulation-flocculation process as described in Chapter 4, or in the sedimentation process as described in Chapter 5.

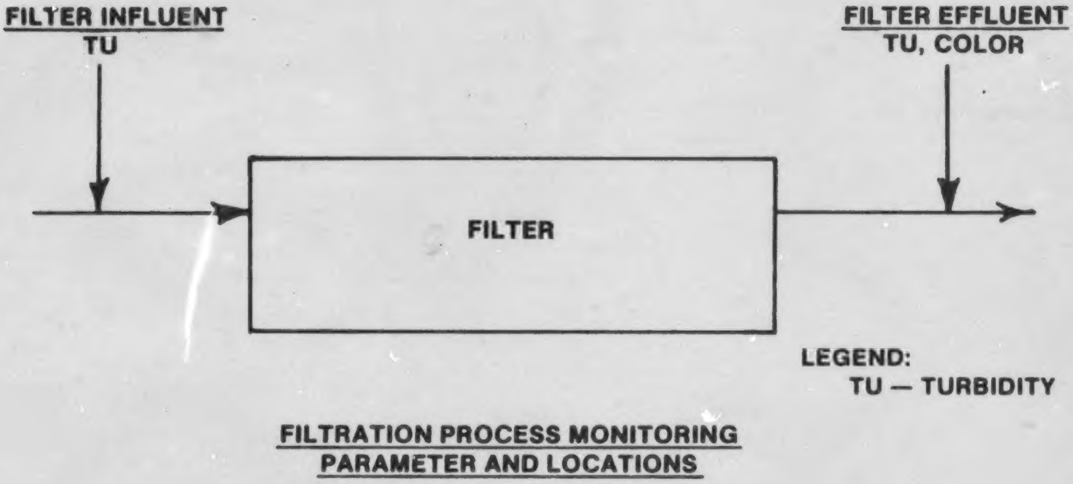


Fig. 6.17 Filtration process monitoring guidelines and locations

At least once a year examine the filter media and evaluate its overall condition. Measure the filter media thickness for an indication of media loss during the backwashing process. Measure mud ball accumulation in the filter media to evaluate the effectiveness of the overall backwashing operation (see Appendix A, "Mud Ball Evaluation Procedure" at the end of this chapter).

Routinely observe the backwash process to qualitatively assess process performance. Watch for media boils (uneven flow distribution) during backwashing, media carryover into the wash water trough, and clarity of the waste washwater near the end of the backwash cycle.

Upon completion of the backwash cycle, observe the condition of the media surface and check for filter sidewall or media surface cracks. Remedial or corrective actions are described in Section 6.8. You should routinely inspect physical facilities and equipment as part of good housekeeping and maintenance practice. Correct or report abnormal equipment conditions to any maintenance personnel.

Never "bump" a filter to avoid backwashing. Bumping is the act of opening the backwash valve during the course of a filter run to dislodge the trapped solids and increase the length of the filter run. This is *NOT* a good practice. If your plant has an on-line turbidimeter on the filter effluent, you will get caught.

A summary of routine filtration process actions is given in Table 6.2.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 241.

6.7A What is the most important water quality indicator used to monitor the filtration process?

6.7B How can filter effluent turbidity be measured on a continuous basis?

6.7C List some of the typical functions performed by operators in the normal operation of the filtration process.

6.7D What could cause a sudden increase in head loss through a filter?

6.7E How would you change the operation of a filter if there was a sudden increase in head loss through the filter?

6.72 Process Calculations

In the routine operation of the filtration process, you will be expected to perform a variety of process calculations related to filter operation (flow rate, filtration rate), backwashing (backwash rate, surface wash rate), water production, and percent of water production used to backwash filters.

6.720 Filter Efficiency

Normally the efficiency of the filtration process is not calculated as such. The filter effluent turbidity is measured from either a grab sample or an on-line turbidimeter. Whenever the effluent turbidity exceeds 0.5 TU or some other established value, the filter should be backwashed.

6.721 Filtration Rate

Filtration rates are measured in gallons per minute per square foot of filter area (GPM/sq ft), liters per second per square meter of filter area (liters per sec/sq m) or rate of rise in millimeters per second. Filtration rates will vary from 2 to 10 GPM/sq ft (1.36 to 6.79 liters per sec/sq m or 1.36 to 6.79 mm/sec) with most agencies specifying a maximum of 6

TABLE 6.2 SUMMARY OF ROUTINE FILTRATION PROCESS ACTIONS

Monitor Process Performance and Evaluate Water Quality Conditions	Location	Frequency	Possible Operator Actions
Turbidity	infl./effl.	Influent at least once per 8-hr shift. Effluent every 2 hours.[a]	1. Increase sampling frequency when process water quality is variable. 2. Perform Jar Tests if indicated (see procedure in Chapter 4, "Coagulation and Flocculation"). 3. Make necessary process changes. a) Change coagulant. b) Adjust coagulant dosage. c) Adjust flash mixer/flocculator mixing intensity. d) Change chlorine dosage. e) Change filtration rate. f) Backwash filter. 4. Verify response to process changes at appropriate time.
Color	infl./effl.	At least once per 8-hr shift.	
Head Loss		At least three times per 8-hr shift	
Operate Filters and Backwash			
Put filter into service. Change filtration rate. Remove filter from service. Backwash filter. Change backwash rate.	Filter module	Depends on process conditions	See operating procedures in Sections 6.9 and 6.10
Check Filter Media Condition			
Media depth evaluation. Media cleanliness. Cracks or shrinkage.	Filter module	At least monthly.	1. Replace lost filter media. 2. Change backwash procedure. 3. Change chemical coagulants.
Make Visual Observations of Backwash Operation			
Check for media boils. Observe media expansion. Check for media carryover into washwater trough. Observe clarity of wastewater.	Filter module	At least once per day or whenever backwashing occurs when less frequent.	1. Change backwash rate. 2. Change backwash cycle time. 3. Adjust surface wash rate or cycle time. 4. Inspect filter media and support gravel for disturbance.
Check Filtration Process and Backwash Equipment Condition			
Noise Vibration Leakage Overheating	Various	Once per 8-hr shift.	1. Correct minor problems. 2. Notify others of major problems.
Inspect Facilities			
Check physical facilities. Check for algae buildup on filter sidewalls and on washwater troughs.	Various	Once per 8-hr shift.	1. Report abnormal conditions. 2. Remove debris from filter media surfaces. 3. Adjust chlorine dosage to control algae.

[a] Ideally effluent turbidity should be continuously recorded.

GPM/sq ft (4.07 liters per sec/sq m or 4.07 mm/sec) for dual-media units. From a practical standpoint, if your plant has four filters the same size and a plant design flow of 10 MGD, any time more than 2.5 MGD is applied to any filter, you are exceeding the design filtration rate. Problems can develop when design filtration rates are exceeded.

FORMULAS

The filtration rate is described as the flow in gallons per minute (GPM) which is filtered by one square foot of filter surface area (a square one-foot wide and one-foot long). If the flows are given in million gallons per day (MGD), they must be converted to gallons per minute (GPM).

$$\text{Flow, GPM} = \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}$$

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

The flow rate in gallons per minute can be determined by obtaining the flow from a flow meter in millions of gallons per day (MGD) and converting this flow to GPM as shown above. Another approach is to turn off the influent valve to a filter and record the time for the water to drop a specified distance. By calculating the velocity of the dropping water and knowing the surface area of the filter, we can calculate the flow rate in gallons per minute (GPM) or any other desired units.

1. To calculate the velocity of the water dropping above the filter, measure the time for the water to drop a specific distance.

$$\text{Velocity, ft/min} = \frac{\text{Water Drop, ft}}{\text{Time, min}}$$

2. To determine the flow of water through the filter in gallons per minute, multiply the velocity (ft/min) times the area (sq ft) times 7.48 gallons per cubic foot (this converts flow from cubic feet per minute to gallons per minute).

$$\text{Flow, GPM} = (\text{Velocity, ft/min})(\text{Surface Area, sq ft})(7.48\text{ gal/cu ft})$$

The flow rate can also be determined in gallons per minute (GPM) if the total volume of water filtered between filter runs is known. This is done by obtaining the total flow volume in gallons and dividing this value by the length of filter run in hours. If we divide the results by 60 minutes per hour, we will convert the flow from gallons per hour to gallons per minute (GPM).

$$\text{Flow, GPM} = \frac{\text{Total Flow, gallons}}{(\text{Filter Run, hr})(60\text{ min/hr})}$$

The Unit Filter Run Volume (UFRV) is a measure of filter performance. This value is determined by obtaining the total volume of water filtered between filter runs and dividing this number by the surface area of the filter in square feet.

$$\text{UFRV, gal/sq ft} = \frac{\text{Volume Filtered, gal}}{\text{Filter Surface Area, sq ft}}$$

If the filtration rate in gallons per minute per square foot (GPM/sq ft) is known, this number times the length of filter run in hours times 60 minutes per hour will also give the Unit Filter Run Volume.

$$\text{UFRV, gal/sq ft} = \left(\begin{array}{c}\text{Filtration Rate,}\\ \text{GPM/sq ft}\end{array}\right)\left(\begin{array}{c}\text{Filter Run,}\\ \text{hr}\end{array}\right)\left(\begin{array}{c}60\\ \text{min/hr}\end{array}\right)$$

EXAMPLE 1

Calculate the filtration rate in GPM/sq ft for a filter with a surface length of 25 feet and a width of 20 feet when the applied flow is 2 MGD (2 million gallons during a 24-hour period).

Known	Unknown
Length, ft = 25 ft	Filtration Rate, GPM/sq ft
Width, ft = 20 ft	
Flow, MGD = 2 MGD	

1. Convert the flow from MGD to GPM.

$$\begin{aligned}\text{Flow, GPM} &= \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}\\ &= \frac{(2\text{ MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}\\ &= 1389\text{ GPM}\end{aligned}$$

2. Calculate the surface area of the filter in square feet.

$$\begin{aligned}\text{Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (25\text{ ft})(20\text{ ft})\\ &= 500\text{ sq ft}\end{aligned}$$

3. Calculate the filtration rate in gallons per minute per square foot.

$$\begin{aligned}\text{Filtration Rate, GPM/sq ft} &= \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}\\ &= \frac{1389\text{ GPM}}{500\text{ sq ft}}\\ &= 2.8\text{ GPM/sq ft}\end{aligned}$$

EXAMPLE 2

Determine the filtration rate in GPM/sq ft for a filter with a surface length of 30 feet and a width of 20 feet. With the influent valve closed, the water above the filter dropped 12 inches in 5 minutes.

Known	Unknown
Length, ft = 30 feet	Filtration Rate, GPM/sq ft
Width, ft = 20 feet	
Water Drop, in = 12 in	
Time, min = 5 min	

1. Calculate the surface area of the filter in square feet.

$$\begin{aligned}\text{Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (30\text{ ft})(20\text{ ft})\\ &= 600\text{ sq ft}\end{aligned}$$

2. Calculate the velocity of the dropping water in feet per minute.

$$\begin{aligned}\text{Velocity, ft min} &= \frac{\text{Water Drop, ft}}{\text{Time, min}}\\ &= \frac{(12\text{ in})}{(12\text{ in/ft})(5\text{ min})}\\ &= 0.2\text{ ft/min}\end{aligned}$$

3. Determine the flow of water through the filter in gallons per minute.

$$\text{Flow, GPM} = (\text{Velocity, ft/min})(\text{Area, sq ft})(7.48\ \text{gal/cu ft})$$

$$= (0.2\ \text{ft/min})(600\ \text{sq ft})(7.48\ \text{gal/cu ft})$$

$$= 898\ \text{GPM}$$

4. Calculate the filtration rate in gallons per minute per square foot.

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$= \frac{898\ \text{GPM}}{600\ \text{sq ft}}$$

$$= 1.5\ \text{GPM/sq ft}$$

EXAMPLE 3

A filter with media surface dimensions of 42 feet long by 22 feet wide produces a total of 18.5 million gallons during a 73.5-hour long filter run. What is the average filtration rate in GPM/sq ft?

Known	Unknown
Length, ft = 42 ft	Filtration Rate, GPM/sq ft
Width, ft = 22 ft	
Total Flow, MG = 18.5 MG	
Filter Run, hr = 73.5 hr	

1. Find the filter media surface area in square feet.

$$\text{Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

$$= (42\ \text{ft})(22\ \text{ft})$$

$$= 924\ \text{sq ft}$$

2. Calculate the average flow rate in gallons per minute.

$$\text{Flow, GPM} = \frac{\text{Total Flow, gallons}}{(\text{Filter Run, hr})(60\ \text{min/hr})}$$

$$= \frac{18{,}500{,}000\ \text{gallons}}{(73.5\ \text{hr})(60\ \text{min/hr})}$$

$$= 4195\ \text{GPM}$$

3. Determine the average filtration rate in gallons per minute per square foot of surface area.

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Area, sq ft}}$$

$$= \frac{4195\ \text{GPM}}{924\ \text{sq ft}}$$

$$= 4.5\ \text{GPM/sq ft}$$

EXAMPLE 4

Determine the Unit Filter Run Volume (UFRV) for the filter in EXAMPLE 1. The volume of water filtered between backwash cycles was 3.6 million gallons. The filter is 25-feet long and 20-feet wide.

Known	Unknown
Length, ft = 25 ft	UFRV, gal/sq ft
Width, ft = 20 ft	
Volume Filtered, gal = 3,800,000 gal	

Calculate the Unit Filter Run Volume in gallons per square foot of filter surface area.

$$\text{UFRV, gal/sq ft} = \frac{\text{Volume Filtered, gal}}{\text{Filter Surface Area, sq ft}}$$

$$= \frac{3{,}800{,}000\ \text{gal}}{(25\ \text{ft})(20\ \text{ft})}$$

$$= 7600\ \text{gal/sq ft}$$

EXAMPLE 5

Determine the Unit Filter Run Volume (UFRV) for the filter in EXAMPLE 1. The filtration rate was 2.8 GPM/sq ft during a 46-hour filter run.

Known	Unknown
Filtration Rate, GPM/sq ft = 2.8 GPM/sq ft	UFRV, gal/sq ft
Filter Run, hr = 46 hr	

Calculate the Unit Filter Run Volume in gallons per square foot of filter surface area.

$$\text{UFRV, gal/sq ft} = (\text{Filtration Rate, GPM/sq ft})(\text{Filter Run, hr})(60\ \text{min/hr})$$

$$= (2.8\ \text{GPM/sq ft})(46\ \text{hr})(60\ \text{min/hr})$$

$$= 7728\ \text{gal/sq ft}$$

NOTE: The method used to calculate the UFRV for your plant will depend on the information available.

6.722 Backwash Rate

Filter backwash rates are usually given in gallons per minute per square foot (GPM/sq ft) of surface area; or liters per second per square meter (liters per sec/sq m) of surface area; or inches per minute of water "rise rate" (in/min or mm/sec). Backwash rates will vary from 10 to 25 GPM/sq ft (6.8 to 17 liters per sec/sq m or 6.8 to 17 mm/sec). Usually the plant operation and maintenance (O&M) instructions will specify the filter backwash rate in GPM/sq ft or the pumping rate for the backwash pump in GPM. From a practical standpoint, the backwash rate or pumping rate is too low or the length of the backwash cycle too short if the filter is not completely cleaned. This will be obvious if the next filter run is too short or the initial head loss is too high. The backwash pumping or flow rate is too high if excessive amounts of filter media are being lost or disturbed during backwashing. To determine if filter media is being lost, place a burlap bag on the backwash discharge line (if possible) and examine what is caught by the bag. You could also merely observe how much media material remains in the empty wash trough or recovery basin when backwashing is completed.

When filter backwash rates are given in inches per minute (the velocity of the backwash water rising in the filter, such as 24 inches per minute or 10 millimeters per second) you may want to convert this value to other units such as GPM/sq ft. By applying the proper mathematical conversion factors, inches per minute can be converted to gallons per minute per square foot. One GPM per sq ft is approximately equal to 1.6 inches per minute of rise. Most operators and designers use gallons per minute per square foot rather than inches per minute.

FORMULAS

Formulas involving backwash calculations are very similar to the formulas for calculating filtration rates. To calculate the backwash pumping or flow rate in gallons per minute (GPM), multiply the filter surface area in square feet times the desired backwash rate in gallons per minute per square foot.

$$\text{Backwash Pumping Rate, GPM} = (\text{Filter Area, sq ft})(\text{Backwash Rate, GPM/sq ft})$$

To calculate the volume of backwash water needed, multiply the backwash flow in gallons per minute (GPM) times the backwash time in minutes.

$$\text{Backwash Water, gallons} = (\text{Backwash Flow, GPM})(\text{Backwash Time, min})$$

To convert a backwash flow rate from gallons per minute per square foot (GPM/sq ft) to inches per minute of rise, divide by 7.48 gallons per cubic foot to obtain the rise rate in feet per minute. Multiply by 12 inches per foot to obtain the backwash rate in inches per minute of rise.

$$\text{Backwash, in/min} = \frac{(\text{Backwash, GPM/sq ft})(12\text{ in/ft})}{(7.48\text{ gal/cu ft})}$$

To determine the percent of water used for backwashing, divide the gallons of backwash water by the gallons of water filtered and multiply by 100 percent.

$$\text{Backwash, \%} = \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}$$

EXAMPLE 6

Determine the backwash pumping rate in gallons per minute (GPM) for a filter 30 feet long and 20 feet wide if the desired backwash rate is 20 GPM/sq ft.

Known		Unknown
Length, ft	= 30 ft	Backwash Pumping, Rate, GPM
Width, ft	= 20 ft	
Backwash Rate, GPM/sq ft	= 20 GPM/sq ft	

1. Calculate the area of the filter.

$$\begin{aligned}\text{Filter Area, sq ft} &= (\text{Length, ft})(\text{Width, ft})\\ &= (30\text{ ft})(20\text{ ft})\\ &= 600\text{ sq ft}\end{aligned}$$

2. Determine the backwash pumping rate in GPM.

$$\begin{aligned}\text{Backwash Pumping Rate, GPM} &= (\text{Filter Area, sq ft})(\text{Backwash Rate, GPM/sq ft})\\ &= (600\text{ sq ft})(20\text{ GPM/sq ft})\\ &= 12{,}000\text{ GPM}\end{aligned}$$

NOTE: Large filter areas may have backwash tanks instead of pumps because of the large flows required. Variable rate pumps are also used which are programmed to start with a low backwash rate and then to increase the rate.

EXAMPLE 7

Determine the volume or amount of water required to backwash the filter in EXAMPLE 3 if the filter is backwashed for 8 minutes. The backwash pumping rate calculated in EXAMPLE 3 is the same as the desired flow rate from the backwash tank.

Known		Unknown
Backwash Flow Rate, GPM	= 12,000 GPM	Backwash Water, gallons
Backwash Time, min	= 8 min	

1. Calculate the volume of backwash water required in gallons.

$$\begin{aligned}\text{Backwash Water, gallons} &= (\text{Backwash Flow, GPM})(\text{Backwash Time, min})\\ &= (12{,}000\text{ gal/min})(8\text{ min})\\ &= 96{,}000\text{ gallons}\end{aligned}$$

EXAMPLE 8

How deep must the water be in the backwash tank in EXAMPLE 6 be to be able to backwash the filter for 8 minutes? The backwash tank is 50 feet in diameter.

Known		Unknown
Backwash Water, gallons	= 96,000 gallons	Water Depth, ft
Tank Diameter, feet	= 50 ft	

1. Convert volume of backwash water from gallons to cubic feet.

$$\begin{aligned}\text{Backwash Water, cu ft} &= \frac{\text{Backwash Water, gallons}}{7.48\text{ gallons/cu ft}}\\ &= \frac{96{,}000\text{ gallons}}{7.48\text{ gallons/cu ft}}\\ &= 12{,}834\text{ cu ft}\end{aligned}$$

BACKWASH WATER

2. Calculate the depth of water required in the backwash tank.

$$\text{Water Depth, ft} = \frac{\text{Backwash Water Volume, cu ft}}{\text{Tank Area, sq ft}}$$

$$= \frac{12{,}834 \text{ cu ft}}{(0.785)(50 \text{ ft})^2}$$

$$= \frac{12{,}834 \text{ cu ft}}{1963.5 \text{ sq ft}}$$

$$= 6.54 \text{ ft}$$

You should have at least 6.6 feet or 6 ft-7 inches of water in the backwash tank.

EXAMPLE 9

Convert a filter backwash rate from 25 gallons per minute per square foot to inches per minute of rise.

Known	Unknown
Backwash, GPM/sq ft = 25 GPM/sq ft	Backwash, in/min

Convert the backwash rate from GPM/sq ft to inches/minute.

$$\text{Backwash, in/min} = \frac{(\text{Backwash, GPM/sq ft})(12 \text{ in/ft})}{7.48 \text{ gal/cu ft}}$$

$$= \frac{(25 \text{ GPM/sq ft})(12 \text{ in/ft})}{7.48 \text{ gal/cu ft}}$$

$$= 40 \text{ in/min}$$

EXAMPLE 10

During a filter run the total volume of water filtered was 18.5 million gallons. When the filter was backwashed, 96,000 gallons of water was used. Calculate the percent of the product water used for backwashing.

Known		Unknown
Water Filtered, gal	= 18,500,000 gal	Backwash, %
Backwash Water, gal	= 96,000 gal	

Calculate the percent of water used for backwashing.

$$\text{Backwash, \%} = \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}$$

$$= \frac{(96{,}000 \text{ gal})(100\%)}{18{,}500{,}000 \text{ gal}}$$

$$= 0.5\%$$

6.73 Recordkeeping

Recordkeeping is one of the most important *ADMINISTRATIVE* jobs required of water treatment plant operators.

You will maintain a daily operations log of process performance data and water quality characteristics. Accurate records of the following items should be maintained:

1. Process water quality (turbidity and color);
2. Process operation (filters in service, filtration rates, loss of head, length of filter runs, frequency of backwash, backwash rates, and UFRV);
3. Process water production (water processed, amount of backwash water used, and chemicals used);
4. Percent of water production used to backwash filters; and
5. Process equipment performance (types of equipment in operation, equipment adjustments, maintenance procedures performed, and equipment calibration).

Entries in logs should be neat and legible, should reflect the date and time of an event, and should be initialed by the operator making the entry.

Figure 6.18 is an example of a typical daily operating record for a water treatment plant with sixteen filters. If your plant has four filters or even only one filter, you could develop a similar record sheet for your plant.

1. Sheet No. 311 indicates that November 7 (today's date) is the 311th day of the year.
2. Filter number one was last backwashed (or started) on November 4 at 8:30 a.m. Today the filter was backwashed (stopped) at 11:30 a.m. on November 7.
3. The filter operated 15 hours, 30 minutes (24:00 − 8:30 = 15:30) on November 4, 24 hours on November 5, and 24 hours on November 6 for a previous total of 63 hours and 30 minutes (15:30 + 24:00 + 24:00 = 63:30). Today (November 7) the filter operated for 11 hours and 30 minutes. Therefore, the total hours operated was 75:00 hours (11:30 + 63:30 = 75:00).
4. The head loss through the filter at the start was 0.50 ft and 6.00 ft at the end of the filter run on November 7.
5. The actual backwash time was 6 minutes and 0.14 million gallons of water was used to backwash the filter.
6. Filter number 9 was also backwashed today.
7. The data sheet is not completed for the remaining filters.
8. At the bottom of the data sheet, a summary of the performance of all 16 filters is provided. On November 7 two filters were washed.
9. Filter No. 1 ran for 75 hours and Filter No. 9 ran for 100 hours for an average run time per filter of 87.5 hours.

$$\text{Average Run, hrs} = \frac{\text{Total Length of Run for Each Filter Washed, hrs}}{\text{Total Number of Filters Washed}}$$

$$= \frac{75 \text{ hrs} + 100 \text{ hrs}}{2}$$

$$= 87.5 \text{ hrs}$$

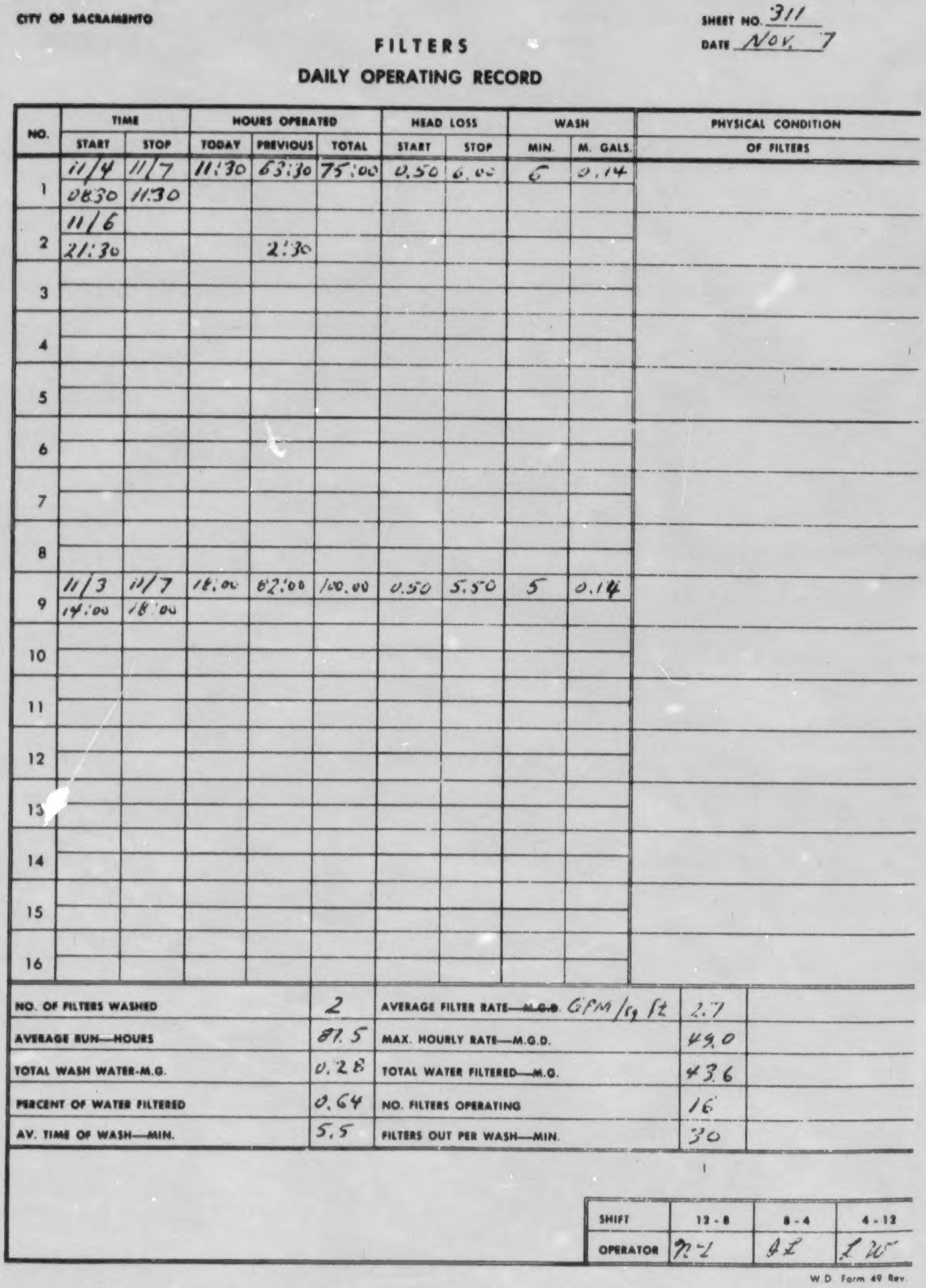
10. Total water used to wash filters is the sum of the water used to wash each filter (0.14 M Gal + 0.14 M Gal = 0.28 M Gal).
11. Percent of water filtered is the Total Wash Water divided by the Total Water Filtered times 100 percent. This value is the percent of water filtered which is used for backwashing.

$$\text{Water Filtered, \%} = \frac{(\text{Total Wash Water, M Gal})(100\%)}{\text{Total Water Filtered, M Gal}}$$

$$= \frac{(0.38 \text{ M Gal})(100\%)}{43.6 \text{ M Gal}}$$

$$= 0.87\%$$

12. Average time of washing filters is the average of the two wash times (6 min + 5 min)/2 = 5.5 min.



CITY OF SACRAMENTO

SHEET NO. 311
DATE Nov. 7

FILTERS
DAILY OPERATING RECORD

NO.	TIME		HOURS OPERATED			HEAD LOSS		WASH		PHYSICAL CONDITION
	START	STOP	TODAY	PREVIOUS	TOTAL	START	STOP	MIN.	M. GALS.	OF FILTERS
1	11/4 0830	11/7 11:30	11:30	63:30	75:00	0.50	6.00	6	0.14	
2	11/6 21:30			2:30						
3										
4										
5										
6										
7										
8										
9	11/3 14:00	11/7 18:00	18:00	82:00	100.00	0.50	5.50	5	0.14	
10										
11										
12										
13										
14										
15										
16										

NO. OF FILTERS WASHED	2	AVERAGE FILTER RATE—~~M.G.D.~~ GFM/sq ft	2.7
AVERAGE RUN—HOURS	81.5	MAX. HOURLY RATE—M.G.D.	49.0
TOTAL WASH WATER-M.G.	0.28	TOTAL WATER FILTERED—M.G.	43.6
PERCENT OF WATER FILTERED	0.64	NO. FILTERS OPERATING	16
AV. TIME OF WASH—MIN.	5.5	FILTERS OUT PER WASH—MIN.	30

SHIFT	12 - 8	8 - 4	4 - 12
OPERATOR	R-L	JL	LW

W.D. Form 49 Rev.

Fig. 6.18 Filter daily operating record
(Permission of City of Sacramento)

13. The average filter rate in gallons per minute per square foot is the average flow in gallons per minute divided by the total surface area for all filters in service. The average daily flow in million gallons per day (MGD) must be converted to GPM. There are 16 filters with a surface area of 700 square feet each for a total of 11,200 square feet of filter surface area.

$$\text{Filtration Rate, GPM/sq ft} = \frac{(\text{Total Water Filtered, MG/day})\ (1{,}000{,}000)}{(\text{Filter Surface Area, sq ft})\ (1\ \text{Million})\ (24\ \text{hr/day})\ (60\ \text{min/hr})}$$

$$= \frac{(43.6\ \text{MG/day})\ (1{,}000{,}000)}{(11{,}200\ \text{sq ft})\ (1\ \text{Million})\ (24\ \text{hr/day})\ (60\ \text{min/hr})}$$

$$= 2.7\ \text{GPM/sq ft}$$

14. The maximum hourly rate in MGD is the maximum flow treated by the filters during any time period during the day.
15. The total water filtered is the volume of water filtered during the 24-hour period for November 7. This value can be obtained from the filter effluent flow meter or other appropriate plant flow meter.
16. The number of filters operating on November 7 was sixteen.
17. When a filter is out of service for backwashing, the total time for the entire backwash cycle was 30 minutes.

6.74 Filter Monitoring Instrumentation

To evaluate filtration process efficiency, you will need to be familiar with the measurement of turbidity. This test can be readily performed in the laboratory with the aid of a turbidimeter. In addition, on-line or continuous water quality monitors, such as turbidimeters (Figure 6.14), will give you an early warning of process failure and will aid in making a rapid assessment of process performance.

You will also need to be familiar with methods used to measure filter media loss and to determine the presence of mud balls in the filter media (see Appendix A at the end of this chapter). .

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 241.

6.7F What types of records should be kept when operating a filtration process?

6.7G Calculate the percent of water filtered used for backwashing if a filtration plant uses 0.12 million gallons for backwashing during a period when a total of 5 million gallons of water was filtered.

6.8 OPERATING PROCEDURES ASSOCIATED WITH ABNORMAL PROCESS CONDITIONS

6.80 Indicators of Abnormal Conditions

Abrupt changes in water quality indicators such as turbidity, pH, alkalinity, threshold odor number (TON), temperature, chlorine demand (source water), chlorine residual (in-process), or color are signals that the operator should immediately review the performance of the filtration process, as well as pretreatment processes (coagulation, flocculation, and sedimentation).

During a normal filter run, watch for rapid changes in head loss buildup in the filter and turbidity breakthrough. Significant changes in either of these guidelines may indicate an upset or failure in the filtration process or pretreatment processes. Other indicators of abnormal conditions are as follows:

1. Mud balls in filter media,
2. Media cracking or shrinkage,
3. Media boils during backwash,
4. Excess media loss or visible disturbance,
5. Short filter runs,
6. Filters that will not come clean during backwash, and
7. Algae on walls and media.

6.81 Process Actions

Significant changes in source water turbidity levels, either increases or decreases, require immediate verification of the effectiveness of the filtration process in removing suspended solids and floc. A quick determination of filtration removal efficiency can be made by comparing filter influent and effluent turbidity levels with those of recent record.

In the event that filter turbidity removal efficiency is decreasing, look first at the performance of the coagulation and flocculation processes, to determine if the coagulant dosage is correct for current conditions. This may require performing jar tests in the laboratory as described in Chapter 4, "Coagulation and Flocculation," to properly assess treatment conditions.

Increases in source water turbidity and resultant increases in coagulant feed rates may impose a greater load on the filters if the majority of suspended solids and floc are not removed in the settling basins. This condition may require that you decrease filtration rates (put additional filters into service) or backwash filters more frequently.

If pretreatment processes do not readily respond to source water quality changes, it may be necessary to add filter-aid chemicals at the filter influent to improve filtration solids removal efficiency. Filter-aid chemicals such as nonionic polymers have proven to be effective in improving filtration performance when fed at low dosage rates (parts per billion). However, care must be exercised in selecting the appropriate feed rate, since overdosing can cause sealing of the filter media resulting in drastically shortened filter runs. Generally, appropriate feed rates are established by trial and experience since this procedure is not easily simulated (duplicated) in the laboratory.

For example, you could begin feeding a polymer as a filter aid at 0.10 mg/*L*. Note the effectiveness of the results by observing (1) removal of floc, (2) filter effluent turbidity, and (3) length of filter run. Compare these results to results without the polymer. If there was an improvement in filter effluent quality (reduction of turbidity) but a decrease in length of filter run, decrease the polymer feed. Continue to decrease the polymer feed until there is either a lessening of filter effluent quality or filter run time is maximized.

Changes in source water quality such as alkalinity and pH may also affect filtration performance through decreased coagulation-flocculation process performance. This is particularly evident when source water quality changes result from precipitation and runoff, or algal blooms in a source water reservoir. Again, use of filter-aids may improve filtration efficiency until other pretreatment processes are stabilized.

Increases in filter effluent turbidity may also result from floc carryover from the sedimentation process. As described in Chapter 4, "Coagulation and Flocculation," the optimum floc size developed in the flocculation process ranges from about 0.1 to 3.0 mm. In conventional filtration, the optimum floc size is closer to 3.0 mm for settling purposes. However, in the direct filtration process (no sedimentation step) the optimum floc size is closer to 0.1 mm to permit depth penetration of the filter media. When larger floc is not removed in sedimentation (too light), it will be carried over into the filters causing rapid media surface clogging. Hydraulic forces in the filter will shear weak flocs, further contributing to turbidity breakthrough. Reevaluation of coagulation-flocculation and sedimentation performance may be required if floc carryover into the filters reduces filtration efficiency. The size of floc can be estimated by observation, as it is seldom necessary to make an accurate measurement of floc size.

Short filter runs may result from increased solids loading or filter-aid overdosing, excessively high filtration rates, excessive mud ball formation in the filter media, or clogging of the filter underdrain system. Possible corrective actions are summarized in Table 6.3.

If you encounter backwash problems such as media boils, media loss, or failure of the filter to come clean during the backwash process, take immediate corrective actions. Generally, these problems can be solved by adjusting backwash flow rates, surface wash flow rate or duration, or adjusting the time sequence or duration of the backwash cycle. In filters with nozzle-type underdrains, boils are often the result of nozzle failure. In this situation the filter should be taken out of service and the nozzles replaced. Possible operator actions are summarized in Table 6.3.

Problems within the filter itself, such as mud ball formation or filter cracks and shrinkage, result from ineffective or improper filter backwashing. Correction of these conditions will require evaluation and modification of backwash procedures.

Table 6.3 gives a summary of filtration process problems, how to identify the causes of problems, and also how to correct the problems.

If filter beds are not thoroughly washed, material filtered from the water is retained on the surface of the filter. This material is sufficiently adhesive to form minute balls. In time these balls of material come together in clumps to form larger masses of mud balls. Usually as time goes on, filter media becomes mixed in to give it additional weight. When the mass becomes great enough, it causes the mud balls to sink into the filter bed. These mud balls, if allowed to remain, will cause clogged areas in the filter. Generally, proper surface washing will prevent mud ball formation.

6.82 Air Binding[17]

Shortened filter runs can occur because of air bound filters. This is caused by the release of dissolved air in saturated cold water due to a decrease in pressure. Air is released from the water when passing through the filter bed by differences in pressure produced by friction through the bed. Subsequently the released air is entrapped in the filter bed. Air binding will occur more frequently when large head losses are allowed to develop in the filter. Whenever a filter is operated to a head loss which exceeds the head of water over the media, air will be released. Air bound filters are objectionable because the air prevents water from passing through the filter and causes shortened filter runs. When an air bound filter is backwashed, the released air can damage the filter media. When air is released during backwashing, the media becomes suspended in the wash water and is carried out of the filter, thus being no longer available for filtration.

6.83 Excessive Head Loss

If excessive head losses through a filter remain after backwashing, the filter underdrain system and the head loss measurement equipment should be checked. High head losses can be caused by reduction in the size and number of underdrain openings. The underdrain openings can be reduced in size or clogged due to media and also from corrosion or chemical deposits. Excessive or abnormal head loss readings also may be caused by malfunctioning head loss measurement equipment.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 241.

6.8A How would you identify an upset or failure in the filtration process or pretreatment processes?

6.8B List the indicators of abnormal filtration process conditions.

6.8C How is filtration removal efficiency determined?

6.8D What problems may be encountered during backwash?

6.8E How does a filter become air bound?

6.9 STARTUP AND SHUTDOWN PROCEDURES

6.90 Conditions Requiring Implementation of Startup and Shutdown Procedures

Unlike the previously discussed treatment processes (coagulation, flocculation, and sedimentation), startup or shutdown of the filtration process *IS* a routine operating procedure in most water treatment plants. This is true even if the treatment plant is operated on a continuous basis, since it is common practice for a filter module to be brought into service or taken off line for backwashing. Clean filters may

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[17] *Air Binding. A situation where air enters the filter media. Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.*

TABLE 6.3 FILTRATION PROCESS TROUBLESHOOTING

Source Water Quality Changes	Operator Actions	Possible Process Changes
Turbidity Temperature Alkalinity pH Color Chlorine demand	1. Perform necessary analysis to determine extent of damage. 2. Assess overall process performance. 3. Perform jar tests if indicated. 4. Make appropriate process changes (see right hand column, Possible Process Changes). 5. Increase frequency of process monitoring. 6. Verify response to process changes at appropriate time (be sure to allow sufficient time for change to take effect). 7. Add lime or caustic soda if alkalinity is low.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of sludge removal (increase or decrease). 5. Change filtration rate (add or delete filters). 6. Start filter-aid feed. 7. Adjust backwash cycle (rate, duration).
Sedimentation Process Effluent Quality Changes		
Turbidity or floc carryover	1. Assess overall process performance. 2. Perform jar tests if indicated. 3. Make appropriate process changes. 4. Verify response to process changes at appropriate time.	1. Same as for source water quality changes.
Filtration Process Changes/Problems		
Head loss increase Short filter runs Media surface sealing Mud balls Filter media cracks, shrinkage Filter will not come clean Media boils Media loss	1. Assess overall process performance. 2. Perform jar tests if indicated. 3. Make appropriate process changes. 4. Verify response to process changes at appropriate time.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of sludge removal. 5. Decrease filtration rate (add more filters). 6. Decrease or terminate filter-aid feed. 7. Adjust backwash cycle (rate, duration). 8. Manually removal mud balls (hoses or rakes). 9. Replenish lost media. 10. Excessive head loss may be caused by underdrain openings becoming plugged with filter media or by corrosion and chemical deposits.
Filter Effluent Quality Changes		
Turbidity breakthrough Color pH Chlorine demand	1. Assess overall process performance. 2. Perform jar tests if indicated. 3. Verify process performance: (a) Coagulation-flocculation process (see Chapter 4, "Coagulation and Flocculation"), (b) Sedimentation process (see Chapter 5, "Sedimentation"), (c) Filtration process (see above suggestions). 4. Make appropriate process changes. 5. Verify response to process changes at appropriate time.	1. Change coagulant. 2. Adjust coagulant dosage. 3. Adjust flash mixer/flocculator mixing intensity. 4. Change frequency of sludge removal. 5. Decrease filtration rate (add more filters). 6. Start filter-aid feed. 7. Change chlorine dosage.

be put into service when a dirty filter is removed for backwashing, when it is necessary to decrease filtration rates, or to increase plant production as a result of increased demand for water. However, most plants keep all filters on line except for backwashing and in service except for maintenance. Filters are routinely taken off-line for backwashing when the media becomes clogged with particulates, turbidity breakthrough occurs, or demands for water are reduced.

6.91 Implementation of Startup/Shutdown Procedures

Typical actions performed by the operator in the startup and shutdown of the gravity filtration process are outlined below. These procedures also generally apply to pressure filters. While some of these concepts also apply to diatomaceous earth filtration, the manufacturer's operating procedures will set forth more specific criteria.

Figures 6.19 and 6.20 illustrate sectional views of typical gravity filters. The figures show the valve positions and flow patterns in the filtration and backwash modes of filter operation.

6.910 Filter Check-out Procedures

Check operational status of filter.

1. Be sure filter media and washwater troughs are clean of all debris such as leaves, twigs, and tools.
2. Check and be sure all access covers and walkway gratings are in place.
3. Make sure process monitoring equipment such as head loss and turbidity systems are operational.
4. Check source of backwash water to insure it is ready to go. This could be an elevated washwater tank, pumps, or other source.

6.911 Backwash Procedures

1. Filters should be washed before placing them in service.
   a. If filters are to be washed using automatic equipment, check to be sure length of cycle times set for backwash and surface wash cycles are "correct." "Correct" times vary from plant to plant and time of year. These settings should be based on physical observations of actual time required to clean the filter. A good idea is to wash filters usually washed automatically once in a while using a manual procedure to insure efficient cleaning of the media during the wash cycle.
   b. The surface wash system should be activated just before the backwash cycle starts to aid in removing and breaking up solids on the filter media and to prevent the development of mud balls. The surface wash system should be stopped before completion of the backwash cycle to permit proper reclassification (settling) of the filter media.
   c. A filter wash should begin slowly (about 5 GPM/square foot, 3.4 liters per sec/sq m or 3.4 mm/sec) for about one minute to permit purging (removing) of any entrapped air from the filter media, and also to provide uniform expansion of the filter bed. After this period the full backwash rate can be applied (15 to 25 GPM/sq ft, 10 to 17 liters per sec/sq m or 10 to 17 mm/sec). Sufficient time should be allowed for cleaning of the filter media. Usually when the backwash water coming up through the filter becomes clear, the media is clean. This generally takes from three to eight minutes. If flooding of washwater troughs or carryover of filter media is a problem, the backwash rate must be reduced: This may be accomplished by adjusting the master backwash valve, thereby throttling the amount of washwater used.
   d. In many water treatment plants waste backwash water is either directly recycled through the plant or is allowed to settle in a tank, pond, or basin and then the supernatant (clear, top portion of water) pumped back to be recycled through the plant. Usually it is best to gradually add the waste backwash water to the headworks of the treatment plant (before the flash mixer). This is because a large slug of waste backwash water will require changes in chemical dosages due to the additional flow and increased turbidity.
2. Procedures for backwashing a filter are as follows:
   a. Log length of filter run since last backwash (Figure 6.18),
   b. Close filter influent valve (V-1),
   c. Open drain valve (V-4),
   d. Close filter effluent valve, (V-5),
   e. Start surface wash system (open V-2),
   f. Slowly start backwash system (open V-3),
   g. Observe filter during washing process,
   h. When washwater from filter becomes clear (filter media is clean), close surface wash system valve (V-2),
   i. Slowly turn off backwash water system (close V-3),
   j. Close drain valve (V-4),
   k. Log length of wash and number of gallons of water used to clean filter.

6.912 Filter Startup Procedures

1. After washing the filters they should be eased on-line. With automatic equipment this is generally done by a gradual opening of the filter's effluent valve. Manual operations require a gradual increase of the amount of water treated by the filter. The initial few hours after a filter is placed in service is a time where turbidity breakthrough can pose a problem. For this reason, filters should be eased into service to avoid hydraulic shock loads.
2. Start filter
   a. Slowly open filter influent valve (V-1),
   b. When proper elevation of water is reached on top of filter, filter effluent valve should be gradually opened (V-5). In many systems the filter effluent valve controls the level of water on the filter. This valve adjusts itself to maintain a constant level of water over the filter media regardless of filtration rate.
   c. Some plants have provisions to waste some of the initial filtered water (open V-6). This provision can be very helpful if an initial breakthrough occurs.
   d. Perform turbidity analyses of filtered water and make process adjustments as necessary.

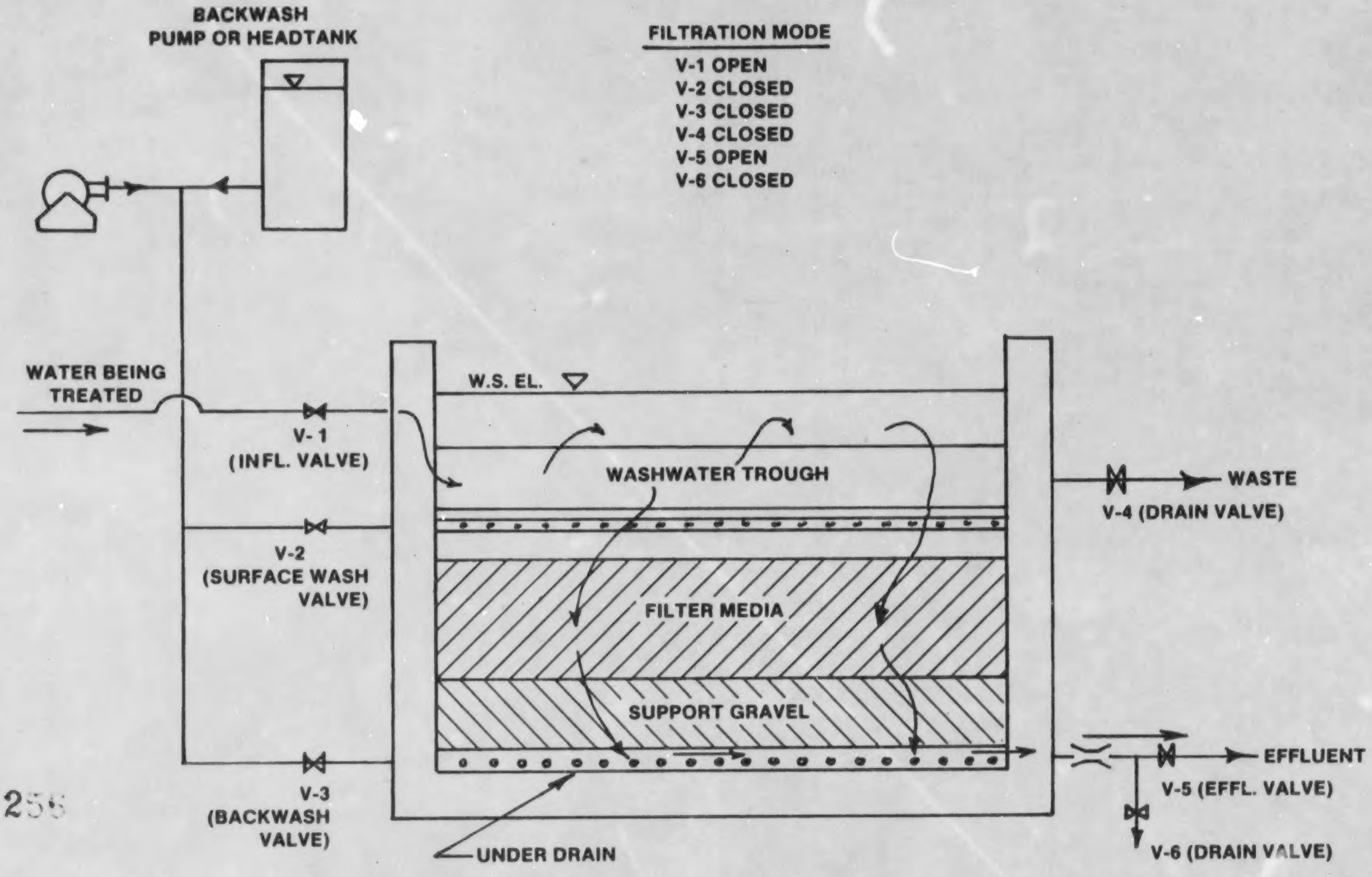

BACKWASH
PUMP OR HEADTANK
FILTRATION MODE
V-1 OPEN
V-2 CLOSED
V-3 CLOSED
V-4 CLOSED
V-5 OPEN
V-6 CLOSED
WATER BEING
TREATED
W.S. EL.
V-1
(INFL. VALVE)
WASHWATER TROUGH
WASTE
V-4 (DRAIN VALVE)
V-2
(SURFACE WASH
VALVE)
FILTER MEDIA
SUPPORT GRAVEL
EFFLUENT
V-5 (EFFL. VALVE)
V-3
(BACKWASH
VALVE)
UNDER DRAIN
V-6 (DRAIN VALVE)

Fig. 6.19 Filtration mode of operation

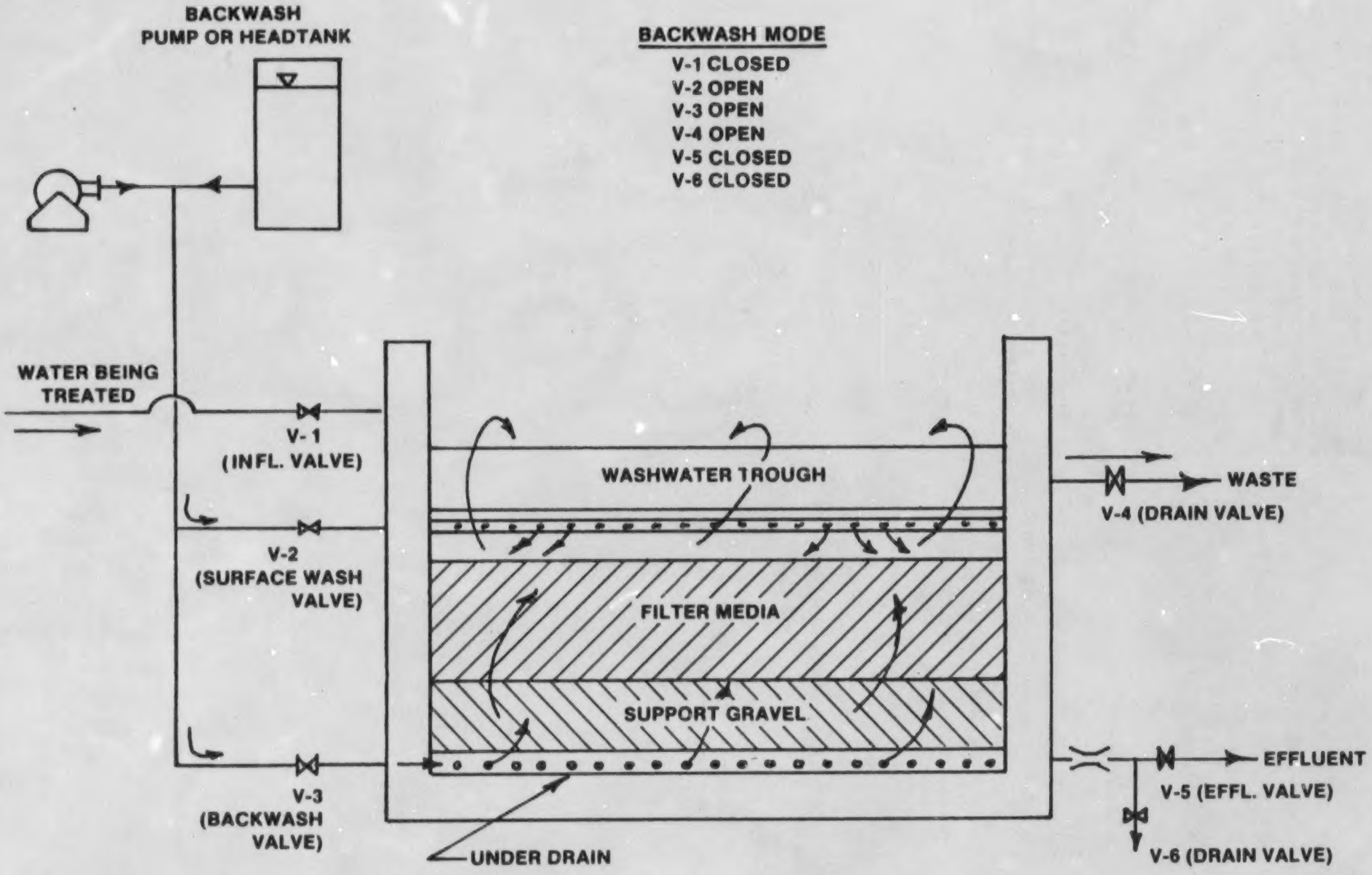

BACKWASH PUMP OR HEADTANK
BACKWASH MODE
V-1 CLOSED
V-2 OPEN
V-3 OPEN
V-4 OPEN
V-5 CLOSED
V-6 CLOSED
WATER BEING TREATED
V-1 (INFL. VALVE)
V-2 (SURFACE WASH VALVE)
V-3 (BACKWASH VALVE)
WASHWATER TROUGH
FILTER MEDIA
SUPPORT GRAVEL
UNDER DRAIN
WASTE
V-4 (DRAIN VALVE)
EFFLUENT
V-5 (EFFL. VALVE)
V-6 (DRAIN VALVE)

Fig. 6.20 Backwash mode of operation

6.913 Filter Shutdown Procedures

1. Remove filter from service by:
   a. Closing influent valve (V-1), and
   b. Closing effluent valve (V-5).
2. Backwash filter (See Section 6.911, "Backwash Provisions").
3. If filter is to be out-of-service for a prolonged period, drain water from filter to avoid algae growths.
4. Note status of filter in operation's log.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 241.

6.9A Under what conditions may (clean) filters be put back into service?

6.9B When are filters routinely taken off-line?

6.9C What should be done if a filter will be out of service for a prolonged period?

6.9D Why should the surface wash system be activated at the start of the backwash cycle?

6.10 PROCESS AND SUPPORT EQUIPMENT OPERATION AND MAINTENANCE

6.100 Types of Equipment

To run a filtration process you must be familiar with the operation and minor (preventive) maintenance of a variety of mechanical, electrical, and electronic equipment including:

1. Filter control valves,
2. Backwash and surface wash pumps,
3. Flow meters and level/pressure gages,
4. Water quality monitors such as turbidimeters,
5. Process monitors (head loss and water level), and
6. Mechanical and electrical filter control systems.

Since a wide variety of mechanical, electrical, and electronic equipment is used in the filtration process, the operator should be familiar with the operation and maintenance instructions for each specific equipment item or control system.

6.101 Equipment Operation

Before starting a piece of mechanical equipment, such as a backwash pump, be sure that the unit has been serviced on schedule and its operational status is positively known.

After startup, *ALWAYS* check for excessive noise and vibration, overheating, and leakage (water, lubricants). When in doubt about the performance of a piece of equipment, refer to the manufacturer's instructions.

Much of the equipment used in the filtration process is automated and only requires limited attention by operators during normal operation. However, periodic calibration and maintenance of this equipment is necessary, and this usually involves special procedures. Detailed operating, repair, and calibration procedures are usually described in the manufacturer's literature.

6.102 Preventive Maintenance Procedures

Preventive maintenance (P/M) programs are designed to assure the continued satisfactory operation of treatment plant facilities by reducing the frequency of breakdown failures. This is accomplished by performing scheduled or routine maintenance on valves, pumps, and other electrical and mechanical equipment items.

In the normal operation of the filtration process, you will be expected to perform routine maintenance functions as part of an overall preventive maintenance program. Typical functions include:

1. Keeping electrical motors free of dirt, moisture, and pests (rodents and birds);
2. Assuring good ventilation (air circulation) in equipment work areas;
3. Checking pumps and motors for leaks, unusual noise and vibrations, or overheating;

4. Maintaining proper lubrication and oil levels;
5. Inspecting for alignment of shafts and couplings;
6. Checking bearings for overheating and proper lubrication;
7. Checking for proper valve operation (leakage or jamming);
8. Checking automatic control systems for proper operation;
9. Checking air/vacuum relief systems for proper functioning, dirt, and moisture;
10. Verifying correct operation of filtration and backwash cycles by observation;
11. Inspecting filter media condition (look for algae and mud balls and examine gravel and media for proper gradation); and
12. Inspecting filter underdrain system (be sure underdrain openings are not becoming clogged due to media, corrosion or chemical deposits).

Accurate recordkeeping is the most important element of any successful preventive maintenance program. These records provide operation and maintenance personnel with clues for determining the causes of equipment failures. They frequently can be used to forecast impending failures thus preventing costly repairs.

6.103 Safety Considerations

To avoid accidents or injury when working around filtration equipment such as pumps and motors, follow the safety procedures listed below:

ELECTRICAL EQUIPMENT

1. Avoid electrical shock (use protective gloves),
2. Avoid grounding yourself in water or on pipes,
3. Ground all electrical tools,
4. Lock out and tag electrical switches and panels when servicing equipment, and
5. Use the buddy system.

MECHANICAL EQUIPMENT

1. Use protective guards on rotating equipment,
2. Do not wear loose clothing around rotating equipment,

3. Keep hands out of energized valves, pumps and other pieces of equipment, and
4. Clean up all lubricant and chemical spills (slippery surfaces cause bad falls).

OPEN-SURFACE FILTERS

1. Use safety devices such as handrails and ladders,
2. Close all openings and replace safety gratings when finished working, and

3. Know the location of all life preservers, and other safety devices.

VALVE AND PUMP VAULTS, SUMPS, FILTER GALLERIES

1. Be sure all underground or confined structures are free of hazardous atmospheres (toxic or explosive gases, lack of oxygen) by checking with gas detectors,

2. Only work in well-ventilated structures (use air circulation fans), and
3. Use the buddy system.

6.11 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read all of Section A.6, "Force, Pressure, Head."

In Section A.13, "Typical Water Treatment Plant Problems," read and work the problems in Section A.135, "Filtration."

6.12 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 9, "Filtration."
2. *TEXAS MANUAL*, Chapter 9, "Filtration."

6.13 ACKNOWLEDGMENTS

Many of the concepts and procedures discussed in this chapter are based on material obtained from the sources listed below.

1. Stone, B.G. Notes from "Design of Water Treatment Systems," CE-610, Loyola Marymount University, Los Angeles, CA., 1977.
2. *WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES*, American Water Works Association, Third Edition, McGraw-Hill, 1971. Available from Data Processing Department, AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235. Order No. 10008, price to members, $34.10; nonmembers, $42.60.
3. *WATER TREATMENT PLANT DESIGN*, prepared jointly by the American Society of Civil Engineers, American Water Works Association, and Conference of State Sanitary Engineers, AWWA, 1969. Available from Data Processing Department, AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235. Order No. 10006, price to members, $14.40; nonmembers, $18.00.

4. *OPERATION AND MAINTENANCE MANUAL FOR STOCKTON EAST WATER TREATMENT PLANT*, James M. Montgomery, Consulting Engineers, Inc., Walnut Creek, CA., 1979.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 242.

6.10A List the types of equipment used in the filtration process.

6.10B What should be done before starting a piece of mechanical equipment, such as a backwash pump?

6.10C What safety hazards may be encountered when working around mechanical equipment?

End of Lesson 2 of 2 Lessons on FILTRATION

Please answer the discussion and review questions before continuing.

DISCUSSION AND REVIEW QUESTIONS

Chapter 6. FILTRATION

(Lesson 2 of 2 Lessons)

Please write the answers to these questions in your notebook before continuing with the Objective Test on page 242. The problem numbering continues from Lesson 1.

6. How would you monitor a filtration process?
7. How frequently should the performance of the filtration process be evaluated?
8. What would you look for in evaluating the filter media condition after a backwash cycle?
9. Abnormal operation conditions are signaled by sudden changes in what water quality indicators?
10. How could you adjust filter operation if increases in source water turbidity and resultant increases in coagulant feed rates impose a greater load on the plant's active filters?
11. What backwash process adjustments would you make to solve such problems as media boils, media loss, or incomplete cleaning of media?
12. What should you always check for after starting any piece of equipment?

SUGGESTED ANSWERS

Chapter 6. FILTRATION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 201.

6.0A Filtration preceded by coagulation, flocculation, and sedimentation is commonly referred to as *CONVENTIONAL FILTRATION*. In the *DIRECT FILTRATION* process, the sedimentation step is omitted. Flocculation facilities are reduced in size or may be omitted.

6.1A The particle removal mechanisms involved in the filtration process include (1) sedimentation on media, (2) adsorption, (3) biological action, (4) absorption, and (5) straining.

Answers to questions on page 207.

6.2A The four specific classes of filters are (1) gravity filtration, (2) pressure filtration, (3) diatomaceous earth filtration, and (4) slow sand filtration.

6.2B Garnet is a group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron or manganese).

6.2C In most water treatment applications, diatomaceous earth is used for the precoat and body-feed operations.

Answers to questions on page 210.

6.3A Gravel is used to support filter materials.

6.3B Filtration rate is commonly expressed in units of gallons per minute per square foot of filter surface area.

6.3C The major difference between sand and dual-media filters is that sand filters require more frequent backwashing because of their smaller media grain size. Also dual-media filters permit a higher filtration rate without a high head loss.

Answers to questions on page 214.

6.3D The time period before a filter becomes clogged depends on (1) the amount of suspended solids in the water being treated, and (2) the filtration rate.

6.3E A filter is usually operated until just before clogging or breakthrough occurs, a specified time period has passed, or a specific head loss is reached.

6.3F Four surface wash systems for filters include (1) Baylis, (2) fixed grid, (3) rotary, and (4) air scour.

6.3G Filter control systems are provided (1) to control flow rates through the filter, and (2) to maintain an adequate head above the media surface.

Answers to questions on page 220.

6.4A The primary purpose of using activated carbon (granular form) as a filter media is to remove taste- and odor-causing compounds, as well as other trace organics from the water.

6.5A "In-line filtration" refers to the addition of filter-aid chemicals immediately prior to filtration.

6.5B Filter-aid chemicals are usually added just prior to filtration to aid in the solids removal process during normal operation and during periods of pretreatment process upset, or when operating at high filtration rates.

6.5C Direct filtration is used when source waters are low in turbidity, color, plankton, and coliform organisms.

6.6A An operator must be provided with a means to measure (1) filter influent water quality (turbidity), (2) filter performance (head loss buildup rate), and (3) filter effluent water quality (turbidity) in order to control the performance of the filtration process on a day-to-day basis.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 225.

6.7A The most important water quality indicator used to monitor the filtration process is the filter influent and effluent turbidity.

6.7B Filter effluent turbidity is best monitored on a continuous basis by an on-line turbidimeter.

6.7C Typical functions performed by operators in the normal operation of the filtration process include:

1. Monitor process performance;
2. Evaluate water quality conditions (turbidity) and make appropriate changes;
3. Check and adjust process equipment (change chemical feed rate);
4. Backwash filters;
5. Evaluate filter media condition (media loss, mud balls, cracking); and
6. Visually inspect facilities.

6.7D A sudden increase in head loss might be an indication of surface sealing of the filter media (lack of depth penetration).

6.7E If a sudden increase in head loss through a filter occurs, the operation of the filter can be changed by adjusting the filter-aid chemical feed rate or by reducing the filtration rate.

Answers to questions on page 232.

6.7F Types of records that should be kept when operating a filtration process include (1) process water quality, (2) process operation, (3) process water production, (4) percent of water production used to backwash filters, and (5) process equipment performance.

6.7G Calculate the percent of water filtered used for backwashing if a filtration plant uses 0.12 million gallons for backwashing during a period when a total of 5 million gallons of water was filtered.

Known	**Unknown**
Wash Water, MG = 0.12 MG	Water Filtered, %
Water Filtered, MG = 5 MG	

Calculate the percent of water filtered used for backwashing.

$$\text{Water Filtered, \%} = \frac{(\text{Wash Water, M Gal})(100\%)}{\text{Water Filtered, M Gal}}$$

$$= \frac{(0.12 \text{ M Gal})(100\%)}{5 \text{ M Gal}}$$

$$= 2.4\%$$

Answers to questions on page 233.

6.8A Upsets or failures in the filtration process or pretreatment processes may be detected by rapid changes in head loss buildup in the filter and/or turbidity breakthrough.

6.8B The indicators of abnormal filtration process conditions include:

1. Mud balls in filter media,
2. Media cracking or shrinkage,
3. Media boils during backwash,
4. Excess media loss or visible disturbance,
5. Short filter runs,
6. Rapid head loss buildup,
7. Turbidity breakthrough,
8. Filters that will not come clean during backwash, and
9. Algae on walls and media.

6.8C Filtration removal efficiency is determined by comparing filter influent and effluent turbidity levels with those of recent record.

6.8D Problems that may be encountered during backwash include media boils, media loss, and failure of the filter to come clean during the backwash process.

6.8E A filter can become air bound by the release of dissolved air in saturated cold water due to the decrease in pressure. Decreases in pressure occur when water passes through the filter media, especially when the filter operates to a head loss which exceeds the head of water over the media.

Answers to questions on page 238.

6.9A Clean filters are commonly put into service when a dirty filter is removed for backwashing, when it is necessary to decrease filtration rates, or increase plant production as a result of increased demand for water. However, most plants keep all filters on line except for backwashing and in service except for maintenance.

6.9B Filters are routinely taken off-line for backwashing when the media becomes clogged with particulates, turbidity breakthrough occurs, or demands for water are reduced.

6.9C If filter will be out of service for a prolonged period, lower water surface level to below media surface to avoid algae growth.

6.9D The surface wash system should be activated at the start of the backwash cycle to aid in breaking up solids in the filter media and to prevent the development of mud balls.

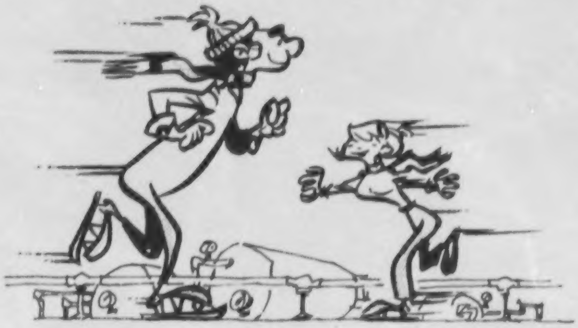
Answers to questions on page 240.

6.10A Types of mechanical, electrical and electronic equipment used in the filtration process include:

1. Filter control valves,
2. Backwash and surface wash pumps,
3. Flow meters and level/pressure gages,
4. Water quality monitors,
5. Process monitors, and
6. Mechanical and electrical filter controls.

6.10B Before starting a piece of mechanical equipment, such as a backwash pump, be sure that the unit is properly serviced and its operational status is positively known.

6.10C Safety hazards which may be encountered when working around mechanical equipment include (1) rotating equipment, (2) slippery surfaces, and (3) energized valves, pumps and other equipment.



OBJECTIVE TEST

Chapter 6. FILTRATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to each multiple choice question.

TRUE FALSE

1. In most types of filtration, particles are removed mainly by straining.
   1. True
   2. False

2. Pressure filters generally are more reliable than gravity filters.
   1. True
   2. False

3. Diatomaceous earth filters may be operated either under a pressure or a vacuum.
   1. True
   2. False

4. Diatomaceous earth filtration is primarily a straining process.
   1. True
   2. False

5. Activated carbon removes all organic compounds with the same degree of efficiency as other filter media.
   1. True
   2. False

6. The larger the floc reaching the filter beds, the longer the filter runs.
   1. True
   2. False

7. Entries in a filter log should include the amount of water used for backwashing.
   1. True
   2. False

8. An accurate measurement of floc sizes is frequently necessary.
   1. True
   2. False

9. Backwashing procedures are abnormal operating conditions for a filter.
   1. True
   2. False

10. The surface wash system should be activated at the end of the backwash cycle to aid in removing entrapped solids from the top portion of the media.
    1. True
    2. False

MULTIPLE CHOICE

11. In the filtration process, water may flow through a bed of
    1. Clay.
    2. Coal.
    3. Cobbles.
    4. Sand.
    5. Straw.

12. The removal efficiency of a filter is based on the
    1. Chemical characteristics of the water being treated.
    2. Degree of pretreatment.
    3. Nature of the suspension.
    4. Operation of filter.
    5. Type of filter.

13. A desirable filter media is
    1. Capable of high ion exchange rates.
    2. Free of impurities.
    3. Inert.
    4. Soft.
    5. Soluble in water.

14. Which is the correct order of filter materials in a multi-media or mixed-media gravity filter (from top to bottom)?
    1. Coal, garnet, sand
    2. Coal, sand, garnet
    3. Garnet, coal, sand
    4. Garnet, sand, coal
    5. Sand, coal, garnet

15. What is the highest possible turbidity reduction you can expect when operating a filtration process under optimum conditions?
    1. 85%
    2. 90%
    3. 95%
    4. 98%
    5. 99.5%

16. What is the primary water quality indicator used to monitor the filtration process?
    1. Coliforms
    2. Head loss build up
    3. Iron and manganese
    4. Tastes and odors
    5. Turbidity

17. Maximum desirable filter effluent turbidity is ___ TU.
    1. 0.5
    2. 1.5
    3. 2.5
    4. 5.0
    5. 10.0

18. The filtration process may be terminated for backwashing on the basis of
    1. Effluent turbidity.
    2. Elapsed run time.
    3. Storage in clear well.
    4. System demand.
    5. Total head loss.

19. Backwash process performance can be evaluated by watching for
    1. Clarity of the wastewater at the end of the backwash cycle.
    2. High head loss during backwashing.
    3. Media boils during backwashing.
    4. Media carryover into the wash water trough.
    5. Presence of coliforms in the backwash water.

20. Usually higher backwash rates are required
    1. At higher water temperatures.
    2. At lower pH values.
    3. At lower water temperatures.
    4. With larger media.
    5. With smaller media.

21. Short filter runs may result from
    1. Clogging of the filter underdrain system.
    2. Excessive mud ball formation in the filter media.
    3. Filter aid overdosing.
    4. High filtration rates.
    5. Increased solids loading.

22. The most important filter effluent water quality change is
    1. Chlorine demand.
    2. Color.
    3. Nutrients.
    4. pH.
    5. Turbidity.

23. Clean filters may be put into service when
    1. A dirty filter is taken off line for maintenance.
    2. Demand for water increases.
    3. Filter effluent turbidity levels decrease.
    4. Filtration rates must be increased.
    5. Plant production must be decreased.

24. What problems are created when the floc which reaches a filter becomes too large? Floc which is too large in size will cause
    1. Cracks to develop in media surface.
    2. Media subsidence.
    3. Overloading of backwash facilities.
    4. Short filter runs.
    5. Top portion of filter will clog rapidly.

25. If the head of water on the filter media of a gravity filter is 6 feet, what is the pressure on the media surface in psi?
    1. 2.6 psi
    2. 6.0 psi
    3. 7.5 psi
    4. 8.3 psi
    5. 13.9 psi

26. Calculate the pressure in pounds per square foot on the bottom of a tank when the water depth is 5 feet.
    1. 37 lbs/sq ft
    2. 42 lbs/sq ft
    3. 78 lbs/sq ft
    4. 156 lbs/sq ft
    5. 312 lbs/sq ft

27. Determine the upward force on the bottom of an empty sedimentation basin caused by a groundwater depth of 6 feet above the tank bottom. The basin is 15 feet wide and 30 feet long.
    1. 6,240 lbs
    2. 28,080 lbs
    3. 56,160 lbs
    4. 84,240 lbs
    5. 168,480 lbs

28. During a 24-hour period a water treatment plant filters 2.2 million gallons. The surface area of the filters is 600 square feet. Determine the filtration rate in gallons per minute per square foot.
    1. 1.1 GPM/sq ft
    2. 1.5 GPM/sq ft
    3. 1.9 GPM/sq ft
    4. 2.5 GPM/sq ft
    5. 6.0 GPM/sq ft

29. Determine the percent of water filtered used for backwashing if a plant filters 2.1 million gallons and 25,000 gallons of filtered water is used for backwashing.
    1. 0.64%
    2. 0.84%
    3. 1.19%
    4. 1.68%
    5. 4.20%

30. Calculate the Unit Filter Run Volume in gallons per square foot if a plant filters 4.2 million gallons before backwashing is required and the filter surface area is 600 square feet.
    1. 6,333 gal/sq ft
    2. 7,000 gal/sq ft
    3. 7,600 gal/sq ft
    4. 8,400 gal/sq ft
    5. 9,600 gal/sq ft

End of Objective Test

APPENDIX

A. MUD BALL EVALUATION PROCEDURE

MUD BALL EVALUATION PROCEDURE[18]

1. Frequency of mud ball evaluation. If mud balls in the top of the filter material are a problem, use this procedure on a monthly basis. If mud balls are not a problem, an annual check is sufficient.
2. Sample for mud balls using mud ball sampler shown in Figure 6.21.
3. Backwash the filter to be sampled and drain the filter to at least 12 inches below the surface of the top media layer (or layer of interest).
4. Push the mud ball sampler 6 inches into the sand. Tilt the handle until it is nearly level and lift the sampler full of media.
5. Empty the contents of the sampler into a bucket.
6. Repeat steps 4 and 5 four more times from different locations in the filter.
7. Use a 10-mesh sieve for separating the mud balls from the media. Hold the sieve in a bucket or tub of water so the sieve is nearly submerged.
8. Take a handful of media from the bucket containing the samples of media and mud balls and place the material in the sieve.
9. Gently raise and lower the sieve about one-half inch at a time until the sand is washed away from the mud balls.
10. Shift the mud balls to one side of the sieve by tipping the submerged sieve and gently shaking the sieve.
11. Repeat steps 8, 9 and 10 until the entire sample has been washed in the sieve and all of the mud balls have been separated from the sand. If there are so many mud balls that the washing process is hindered, move some of the mud balls to the measuring cylinder described in the next step.
12. Use a 1000 m*L* graduated cylinder (a smaller or larger cylinder may be used depending on the volume or amount of mud balls in the sand). Fill the graduated cylinder to the 500 m*L* mark with water.
13. Allow the water to drain from the mud balls on the sieve. When the draining has stopped (no more dripping), transfer the mud balls to the graduated cylinder.
14. Record the new level of water in the graduated cylinder.
15. Determine the "Mud Ball Volume, m*L*," by subtracting 500 from the new level of water.
16. Calculate the volume of mud balls as a percent. The total volume of sand and mud balls sampled was 3,540 m*L* if the "mud ball sampler" was full.

$$\text{Mud Ball Volume, \%} = \frac{(\text{Mud Ball Volume, m}L)\ (100\%)}{3{,}540\ \text{m}L}$$

17. Evaluate the condition of the filtering material using Table 6.4.
18. *NOTE:* Mud balls sink more readily in anthracite than sand. Therefore, modify this procedure to collect samples from the bottom six inches of anthracite.

---

[18] *Procedures in this Appendix were adapted from procedures in WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES, American Water Works Association, Third Edition, McGraw-Hill, 1971. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10008, price to members, $34.10; non-members, $42.60.*

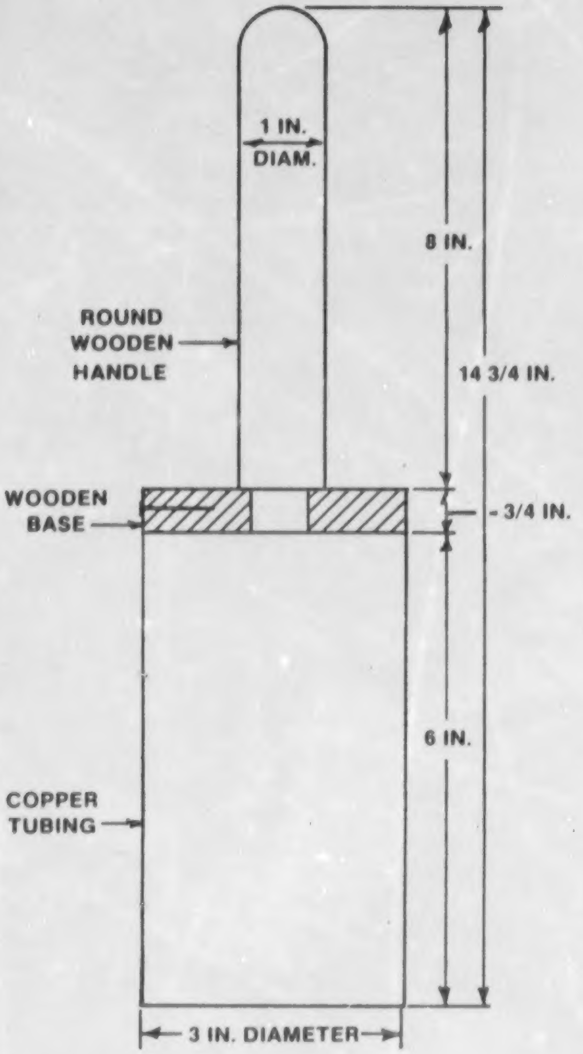


Fig. 6.21 Mud ball sampler

TABLE 6.4 CONDITION OF FILTER

Mud Ball Volume, %	Condition of Filtering Material
0.0 to 0.1	Excellent
0.1 to 0.2	Very Good
0.2 to 0.5	Good
0.5 to 1.0	Fair
1.0 to 2.5	Fairly Bad
2.5 to 5.0	Bad
Over 5.0	Very Bad

EXAMPLE 11

Evaluate the condition of filtering material on the basis of a mud ball evaluation. When the drained mud balls were added to the graduated cylinder, the water rose from the 500 m*L* mark up to the 583 m*L* mark. The total volume sampled was 3,540 m*L*.

Known	Unknown
Initial Cylinder Level, m*L* = 500 m*L*	Condition of Filtering Material
Final Cylinder Level, m*L* = 583 m*L*	
Total Volume Sample, m*L* = 3,540 m*L*	

1. Determine the mud ball volume in milliliters.

$$\begin{aligned}\text{Mud Ball Volume, m}L &= \text{Final Cylinder Level, m}L - \text{Initial Cylinder Level, m}L\\ &= 583\text{ m}L - 500\text{ m}L\\ &= 83\text{ m}L\end{aligned}$$

2. Calculate the mud ball volume as a percent.

$$\begin{aligned}\text{Mud Ball Volume, \%} &= \frac{(\text{Mud Ball Volume, m}L)(100\%)}{3{,}540\text{ m}L}\\ &= \frac{(83\text{ m}L)(100\%)}{3{,}540\text{ m}L}\\ &= 2.3\%\end{aligned}$$

3. Determine the condition of the filtering material from Table 6.4.

From Table 6.4, the condition of a sample with a mud ball volume of 2.3 percent is *FAIRLY BAD.*

CHAPTER 7

DISINFECTION

by

Tom Ikesaki

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Chapter 7. Disinfection

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OBJECTIVES

Chapter 7. DISINFECTION

Following completion of Chapter 7, you should be able to:

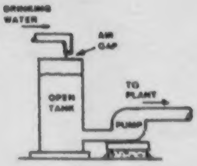
1. Describe the factors that influence disinfection,
2. Explain the process of disinfection using chlorine, hypochlorite and chlorine dioxide,
3. Describe the breakpoint chlorination process,
4. Identify the various points of chlorine application,
5. Operate and maintain chlorination equipment,
6. Handle chlorine safety,
7. Select the proper chlorine dosage,
8. Start up and shut down chlorination equipment,
9. Troubleshoot chlorination systems,
10. Develop and conduct a chlorine safety program, and
11. Operate and maintain disinfection processes other than chlorine.

GLOSSARY

Chapter 7. DISINFECTION

AIR GAP **AIR GAP**

An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because there is no way raw water or any other water can reach the drinking water.



AIR PADDING **AIR PADDING**

Pumping dry air into a container to assist with the withdrawal of a liquid or to force a liquified gas such as chlorine out of a container.

AMBIENT TEMPERATURE (AM-bee-ent) **AMBIENT TEMPERATURE**

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

AMPEROMETRIC (am-PURR-o-MET-rick) **AMPEROMETRIC**

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION (am-PURR-o-MET-rick) **AMPEROMETRIC TITRATION**

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction.

BACTERIA (back-TEER-e-uh) **BACTERIA**

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BREAKPOINT CHLORINATION **BREAKPOINT CHLORINATION**

Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

BUFFER CAPACITY **BUFFER CAPACITY**

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

CARCINOGEN (car-SIN-o-jen) **CARCINOGEN**

Any substance which tends to produce a cancer in an organism.

CATALYST (CAT-uh-LIST) **CATALYST**

A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.

CHLORAMINES (KLOR-uh-means) **CHLORAMINES**

Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

CHLORINATION (KLOR-uh-NAY-shun) **CHLORINATION**

The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors).

CHLORINE DEMAND CHLORINE DEMAND

Chlorine demand is the difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

Chlorine Demand, mg/L = Chlorine Demand, mg/L − Chlorine Residual, mg/L

CHLORINE REQUIREMENT CHLORINE REQUIREMENT

The amount of chlorine which is needed for a particular purpose. Some reasons for adding chlorine are reducing the number of coliform bacteria (Most Probable Number), obtaining a particular chlorine residual, or oxidizing some substance in the water. In each case a definite dosage of chlorine will be necessary. This dosage is the chlorine requirement.

CHLORORGANIC (klor-or-GAN-ick) CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

CHLOROPHENOLIC (klor-o-FEE-NO-lick) CHLOROPHENOLIC

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

COLIFORM (COAL-i-form) COLIFORM

A group of bacteria which are found in the intestine of warm blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

COMBINED AVAILABLE RESIDUAL CHLORINE COMBINED AVAILABLE RESIDUAL CHLORINE

The concentration of residual chlorine which is combined with ammonia (NH_3) and/or organic nitrogen in water as a chloramine (or other chloro derivatives) yet is still available to oxidize organic matter and utilize its bactericidal properties.

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water to produce a combined available residual chlorine. The residual can be made up of monochloramines, dichloramines, and nitrogen trichloride.

DEW POINT DEW POINT

The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air.

DISINFECTION (dis-in-FECK-shun) DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DPD (pronounced as separate letters) DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N, N-diethyl-p-phenylene-diamine.

EDUCTOR (e-DUCK-ter) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump. As an injector, it is used to produce vacuum for chlorinators.

ELECTRON ELECTRON

An extremely small, negatively charged particle; the part of an atom that determines its chemical properties.

ENTERIC ENTERIC

Of intestinal origin, especially applied to wastes or bacteria.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biological catalysts.

FREE AVAILABLE RESIDUAL CHLORINE FREE AVAILABLE RESIDUAL CHLORINE

That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

HEPATITIS (HEP-uh-TIE-tis) HEPATITIS

Hepatitis is an inflammation of the liver usually caused by an acute viral infection. Yellow jaundice is one symptom of hepatitis.

HTH (pronounce as separate letters) HTH

High **T**est **H**ypochlorite. Calcium hypochlorite or $Ca(OCl)_2$.

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

A chemical reaction in which a compound is converted into another compound by taking up water.

HYPOCHLORINATION (hi-po-KLOR-uh-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water for the purpose of disinfection.

HYPOCHLORITE (hi-po-KLOR-ite) HYPOCHLORITE

Chemical compounds containing available chlorine; used for disinfection. They are available as liquids (bleach) or solids (powder, granules and pellets). Salts of hypochlorous acid.

MOTILE (MO-till) MOTILE

Capable of self-propelled movement. A term that is sometimes used to distinguish between certain types of organisms found in water.

MPN (pronounce as separate letters) MPN

MPN is the **M**ost **P**robable **N**umber of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 m*L* of sample water.

NEWTON NEWTON

A force which, when applied to a body having a mass of one kilogram, gives it an acceleration of one meter per second per second.

NITROGENOUS (ny-TRAH-jen-us) NITROGENOUS

A term used to describe chemical compounds (usually organic) containing nitrogen in combined forms. Proteins and nitrates are nitrogenous compounds.

ORTHOTOLIDINE (or-tho-TOL-uh-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual. If chlorine is present, a yellow-colored compound is produced. This reagent is no longer approved for chemical analysis.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDIZING AGENT OXIDIZING AGENT

Any substance, such as oxygen (O_2) and chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a REDUCING AGENT.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PASCAL PASCAL

The pressure or stress of one newton per square meter.

$$1 \text{ psi} = 6895 \text{ Pa} = 6.895 \text{ kN/sq m} = 0.0703 \text{ kg/sq cm}$$

PATHOGENIC ORGANISMS (path-o-JEN-nick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of bacteria which do NOT cause disease. These organisms are called non-pathogenic.

PHENOLIC COMPOUNDS (FEE-noll-LICK) PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene.

POSTCHLORINATION POSTCHLORINATION

The addition of chlorine to the plant effluent, *FOLLOWING* plant treatment, for disinfection purposes.

POTABLE WATER (POE-ta-bl) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

PRECHLORINATION PRECHLORINATION

The addition of chlorine at the headworks of the plant *PRIOR TO* other treatment processes mainly for disinfection and control of tastes, odors, and aquatic growths. Also applied to aid in coagulation and settling.

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters. These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they *MUST* be present in order for THMs to form.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

REDUCING AGENT REDUCING AGENT

Any substance, such as a base metal (iron) or the sulfide ion (S^{2-}), that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.

RESIDUAL CHLORINE RESIDUAL CHLORINE

The amount of free and/or available chlorine remaining after a given contact time under specified conditions.

ROTAMETER (RODE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part of the float.

SAPROPHYTES (SAP-row-FIGHTS) SAPROPHYTES

Organisms living on dead or decaying organic matter. They help natural decomposition of the organic solids in water.

STERILIZATION (stare-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all living microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TOTAL RESIDUAL CHLORINE TOTAL RESIDUAL CHLORINE

The amount of available chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE.

TRIHALOMETHANES (TRI-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resultant compounds (THMs) are suspected of causing cancer.

TURBIDITY (ter-BID-it-tee)	TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

Chapter 7. DISINFECTION

(Lesson 1 of 3 Lessons)

7.0 PURPOSE OF DISINFECTION

7.00 Making Water Safe for Consumption

Our single most important natural resource is water. Without water we could not exist. Unfortunately, safe water is becoming very difficult to find. In the past, safe water could be found in remote areas, but with population growth and related pollution of waters, there are very few natural waters left that are safe to drink without treatment of some kind.

Water is the universal solvent and therefore carries all types of dissolved materials. Water also carries biological life forms which can cause diseases. These water-borne pathogenic organisms are listed in Table 7.1. Most of these organisms and the diseases they transmit are no longer a problem in the United States due to proper water protection, treatment and monitoring. However, many developing regions of the world still experience serious outbreaks of various water-borne diseases.

One of the cleansing processes in the treatment of safe water is called disinfection. Disinfection is the selective destruction of pathogenic organisms. Don't confuse disinfection with sterilization. Sterilization is the complete destruction of all organisms. Sterilization is not necessary in water treatment and is also quite expensive.

7.01 Safe Drinking Water Laws

In the United States, the U.S. Environmental Protection Agency is responsible for setting drinking water standards and for insuring their enforcement. This agency sets federal regulations which all state and local agencies must enforce. The 1976 Primary Drinking Water Regulations contain specific maximum allowable levels of substances known to be hazardous to human health. In addition to describing maximum contaminant levels (MCLs), the 1976 Primary Drinking Water Regulations also give detailed instructions on what to do when you exceed the maximum contaminant level for a particular substance. In Table 7.2 you will find an example of the Primary Drinking Water Regulations for *COLIFORM*[1] bacteria which are supposed to be killed by disinfection.

TABLE 7.1 PATHOGENIC ORGANISMS (DISEASES) TRANSMITTED BY WATER

Bacteria
- Salmonella (salmonellosis)
- Shigella (bacillary dysentery)
- Bacillus typhosus (typhoid fever)
- Salmonella paratyphi (paratyphoid)
- Vibrio cholerae (cholera)

Viruses
- Enterovirus
  - Poliovirus
  - Coxsackie Virus
  - Echo Virus
- Andenovirus
- Reovirus
- Infectious Hepatitis

Intestinal Parasites
- Entamoeba histolytica (amoebic dysentery)
- Giardia lamblia (giardiasis)
- Ascaris lumbricoides (giant roundworm)

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[1] *Coliform (COAL-i-form). A group of bacteria which are found in the intestine of warm blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhabit the intestines of warm blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.*

TABLE 7.2 MICROBIOLOGICAL STANDARDS[a]

Contaminant	Maximum Contaminant Level (MCL)	Monitoring Requirement — Surface Only or Combination	Check Sampling, Reporting, and Public Notice
Coliform Bacteria[b]	*MEMBRANE FILTER* Coliforms shall not exceed: 1 per 100 m*L*, mean of all samples per month, 4 per 100 m*L* in more than one sample if less than 20 samples collected per month, or, 4 per 100 m*L* in more than 5% of samples if 20 or more samples are examined per month. *FERMENTATION TUBE — 10 mL PORTION* Coliforms shall not be present in more than 10% of portions per month, Not more than 1 sample may have 3 or more portions positive when less than 20 samples are examined per month, or Not more than 5% of samples may have 3 or more portions positive when 20 or more samples are examined per month.	Regular time intervals, monthly rate based on population (Table 7.3).	If MCL is exceeded, report to state within 48 hours and notify public. *MEMBRANE FILTER* If a single sample exceeds 4 per 100 m*L*, initiate at least two consecutive daily check samples from one sampling point. Collect additional samples daily or as directed by the state until at least two consecutive daily check samples show less than 1 per 100 m*L*. If any check sample confirms the presence of coliform, report to the state within 48 hours. *FERMENTATION TUBE* If a single sample contains coliform in 3 or more 10 m*L* portions, initiate check sampling as above and continue until at least two consecutive daily check samples show no positive tubes. If any check sample confirms the presence of coliform report to state within 48 hours.

[a] See Chapter 22, "Drinking Water Regulations," and poster provided with this manual for more details.

[b] See Chapter 11, "Laboratory Procedures," for details on how to do the coliform bacteria tests (membrane filter (MF) and multiple-tube fermentation (MPN)).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.0A What are pathogenic organisms?

7.0B What is disinfection?

7.0C Drinking water standards are established by what agency of the United States government?

7.0D MCL stands for what words?

7.1 FACTORS INFLUENCING DISINFECTION

7.10 pH

The pH of water being treated can alter the efficiency of disinfectants. Chlorine, for example, disinfects water much faster at a pH around 7.0 than at a pH over 8.0.

7.11 Temperature

Temperature conditions also influence the effectiveness of the disinfectant. The higher the temperature of the water, the more efficiently it can be treated. Water near 70 to 85°F (21 to 29°C) is easier to disinfect than water at 40 to 60°F (4 to 16°C). Longer contact times are required to disinfect water at lower temperatures. To speed up the process, operators often simply use larger amounts of chemicals. Where water is exposed to the atmosphere, the warmer the water temperature the greater the dissipation rate of chlorine into the atmosphere.

7.12 Turbidity

Under normal operating conditions, the turbidity level of water being treated is very low by the time the water reaches the disinfection process. Excessive turbidity will greatly reduce the efficiency of the disinfecting chemical or process. Studies in water treatment plants have shown that when water is filtered to a turbidity of one unit or less, most of the bacteria have been removed.

The suspended matter itself may also change the chemical nature of the water when the disinfectant is added. Some types of suspended solids can create a continuing demand for the chemical, thus changing the effective germicidal (germ killing) properties of the disinfectant.

7.120 Organic Matter

Organics found in the water can consume great amounts of disinfectants while forming unwanted compounds. *TRIHALOMETHANES*[2] are an example of undesirable compounds formed by reactions between chlorine and certain organics. Disinfecting chemicals often react with organics and *REDUCING AGENTS*[3] (Section 7.13). Then, if any of the chemical remains available after this initial reaction, it can

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[2] *Trihalomethanes (TRI-HAL-o-METH-hanes). Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resultant compounds (THMs) are suspected of causing cancer.*

[3] *Reducing Agent. Any substance, such as a base metal (iron) or the sulfide ion (S^{2-}), that will easily donate (give up) electrons. The opposite is an oxidizing agent.*

TABLE 7.3 COLIFORM SAMPLES REQUIRED PER POPULATION SERVED

Population Served	Minimum Number of Samples per Month
25 to 1,000	1†
1,000 to 2,500	2
2,501 to 3,300	3
3,301 to 4,100	4
4,101 to 4,900	5
4,901 to 5,800	6
5,801 to 6,700	7
6,701 to 7,600	8
7,601 to 8,500	9
8,501 to 9,400	10
9,401 to 10,300	11
10,301 to 11,100	12
11,101 to 12,000	13
12,001 to 12,900	14
12,901 to 13,700	15
13,701 to 14,600	16
14,601 to 15,500	17
15,501 to 16,300	18
16,301 to 17,200	19
17,201 to 18,100	20
18,101 to 18,900	21
18,901 to 19,800	22
19,801 to 20,700	23
20,701 to 21,500	24
21,501 to 22,300	25
22,301 to 23,200	26
23,201 to 24,000	27
24,001 to 24,900	28
24,901 to 25,000	29
25,001 to 28,000	30
28,001 to 33,000	35
33,001 to 37,000	40
37,001 to 41,000	45
41,001 to 46,000	50
46,001 to 50,000	55
50,001 to 54,000	60
54,001 to 59,000	65
59,001 to 64,000	70
64,001 to 70,000	75
70,001 to 76,000	80
76,001 to 83,000	85
83,001 to 90,000	90
90,001 to 96,000	95
96,001 to 111,000	100
111,001 to 130,000	110
130,001 to 160,000	120
160,001 to 190,000	130
190,001 to 220,000	140
220,001 to 250,000	150
250,001 to 290,000	160
290,001 to 320,000	170
320,001 to 360,000	180
360,001 to 410,000	190
410,001 to 450,000	200
450,001 to 500,000	210
500,001 to 550,000	220
550,001 to 600,000	230
600,001 to 660,000	240
660,001 to 720,000	250
720,001 to 780,000	260
780,001 to 840,000	270
840,001 to 910,000	280
910,001 to 970,000	290
970,001 to 1,050,000	300
1,050,001 to 1,140,000	310
1,140,001 to 1,230,000	320
1,230,001 to 1,320,000	330
1,320,001 to 1,420,000	340
1,420,001 to 1,520,000	350
1,520,001 to 1,630,000	360
1,630,001 to 1,730,000	370
1,730,001 to 1,850,000	380
1,850,001 to 1,970,000	390
1,970,001 to 2,060,000	400
2,060,001 to 2,270,000	410
2,270,001 to 2,510,000	420
2,510,001 to 2,750,000	430
2,750,001 to 3,020,000	440
3,020,001 to 3,320,000	450
3,320,001 to 3,620,000	460
3,620,001 to 3,960,000	470
3,960,001 to 4,310,000	480
4,310,001 to 4,690,000	490
More than 4,690,001	500

Source: EPA

† A community water system serving 25 to 1,000 persons, with written permission from the state, may reduce this sampling frequency, except that in no case shall it be reduced to less than one per quarter. The decision by the state will be based on a history of no coliform bacterial contamination for that system and on a sanitary survey by the state showing the water system to be supplied solely by a protected groundwater source; free of sanitary defects.

act as an effective disinfectant. The reactions with organics and reducing agents, however, will have significantly reduced the amount of chemical available for this purpose.

7.121 Inorganic Matter

Inorganic compounds such as ammonia (NH_3) in the water being treated can create special problems. In the presence of ammonia, some oxidizing chemicals form side compounds causing a partial loss of disinfecting power. Silt can also create a chemical demand. It is clear, then, that the chemical properties of the water being treated can seriously interfere with the effectiveness of disinfecting chemicals.

7.13 Reducing Agents

Chlorine combines with a wide variety of materials, especially reducing agents. Most of the reactions are very rapid, while others are much slower. These side reactions complicate the use of chlorine for disinfection. The demand for chlorine by reducing agents must be satisfied before chlorine becomes available to accomplish disinfection. Examples of inorganic reducing agents present in water which will react with chlorine include hydrogen sulfide (H_2S), ferrous ion (Fe^{2+}), manganous ion (Mn^{2+}), and the nitrite ion (NO_2^-). Organic reducing agents in water also will react with chlorine and form chlorinated organic materials of potential health significance.

7.14 Microorganisms

7.140 Number and Types of Microorganisms

Microorganism concentration is important because the higher the number of microorganisms, the greater the demand for a disinfecting chemical. The resistance of microorganisms to specific disinfectants varies greatly. Non-spore-forming bacteria are generally less resistant than spore-forming bacteria. Cysts and viruses can be very resistant to certain types of disinfectants.

7.141 *Removal Processes*

Pathogenic organisms can be removed from water or killed by various physical and chemical water treatment processes. These processes are:

1. *COAGULATION.* Chemical coagulation followed by sedimentation and filtration will remove 90 to 95 percent of the pathogenic organisms, depending on which chemicals are used. Alum usage can increase virus removals up to 99 percent.
2. *SEDIMENTATION.* Properly designed sedimentation processes can effectively remove 20 to 70 percent of the pathogenic microrganisms. This removal is accomplished by allowing the pathogenic organisms (as well as non-pathogenic organisms) to settle out by gravity, assisted by chemical floc.
3. *FILTRATION.* Filtering water through granular filters is an effective means of removing pathogenic and other organisms from water. The removal rates vary from 20 to 99+ percent depending on the coarseness of the filter media and the type and effectiveness of pretreatment.
4. *DISINFECTION.* Disinfection chemicals such as chlorine are added to water to kill pathogenic microorganisms.

In previous chapters, you have already studied the first three processes. The fourth, disinfection, is the subject of this chapter.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.1A How does temperature of the water influence disinfection?

7.1B How does pH influence the effectiveness of disinfection?

7.1C What influence do microorganisms have on disinfection?

7.2 PROCESS OF DISINFECTION

7.20 Purpose of Process

The purpose of disinfection is to destroy harmful organisms. This can be accomplished either physically or chemically. Physical methods may (1) physically remove the organisms from the water or (2) introduce motion that will disrupt the cells' biological activity and kill them.

Chemical methods alter the cell chemistry causing the microorganism to die. The most widely used disinfectant chemical is chlorine. Chlorine is easily obtained, relatively cheap, and most importantly, leaves a *RESIDUAL CHLORINE*[4] that can be measured. Other disinfectants are also used. There has been increased interest in disinfectants other than chlorine because of the *CARCINOGENIC*[5] compounds that chlorine may form (TRIHALOMETHANES or THMs).

This chapter will focus primarily on the use of chlorine as a disinfectant. However, let's take a brief look first at other disinfectant methods and chemicals. Some of these are being more widely applied today because of the potential adverse side effects of chlorination.

7.21 Agents of Disinfection

7.210 *Physical Means of Disinfection*

A. *ULTRAVIOLET RAYS* can be used to destroy pathogenic microorganisms. To be effective, the rays must come in contact with each microorganism. The ultraviolet energy disrupts various organic components of the cell causing a biological change that is fatal to the microorganisms.

This system has not had widespread acceptance because of the lack of measurable residual and the cost of operation. Currently, use of ultraviolet rays is limited to small or local systems and industrial applications. Ocean-going ships have used these systems for their water supply.

B. *HEAT* has been used for centuries to disinfect water. Boiling water for about 15 minutes will destroy essentially all microorganisms. This method is very energy intensive and thus very expensive. The only practical application is in the event of a disaster when individual local users are required to boil their water.

C. *ULTRASONIC WAVES* have been used to disinfect water on a very limited scale. Sonic waves destroy the microorganism by vibration. This procedure is not yet practical and is very expensive.

7.211 *Chemical Disinfectants (Other Than Chlorine)*

A. *IODINE* has been used as a disinfectant in water since 1920, but its use has been limited to emergency treatment of water supplies. Although it has long been recognized as a good disinfectant, iodine's high cost and potential physiological effects (pregnant women can suffer serious side effects) have prevented widespread acceptance. The recommended dosage is two drops of iodine (tincture of iodine which is 7 percent available iodine) in a liter of water.

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[4] *Residual Chlorine. The amount of free and/or available chlorine remaining after a given contact time under specified conditions.*

[5] *Carcinogen (car-SIN-o-jen). Any substance which tends to produce a cancer in an organism.*

B. *BROMINE* has been used only on a very limited scale for water treatment because of its handling difficulties. Bromine causes skin burns on contact. Because bromine is a very reactive chemical, residuals are hard to obtain. This also limits its use. Bromine can be purchased at swimming pool supply stores.

C. *BASES* such as sodium hydroxide and lime can be effective disinfectants but the high pH leaves a bitter taste in the finished water. Bases can also cause skin burns when left too long in contact with the skin. Bases effectively kill all microorganisms (they sterilize rather than just disinfect water). Although this method has not been used on a large scale, bases have been used to sterilize water pipes.

D. *OZONE* has been used in the water industry since the early 1900s, particularly in France. In the United States it has been used primarily for taste and odor control. The limited use in the United States has been due to its high costs, lack of residual, difficulty in storing and maintenance requirements.

Although ozone is effective in disinfecting water, its use is limited by its solubility. The temperature and pressure of water being treated regulate the amount of ozone that can be dissolved in the water. These factors tend to limit the disinfectant strength that can be made available to treat the water.

Many scientists claim that ozone destroys all microorganisms. Unfortunately, significant residual ozone does not guarantee that a water is safe to drink. Organic solids may protect organisms from the disinfecting action of ozone and increase the amount of ozone needed for disinfection.

In addition, ozone residuals cannot be maintained in metallic conduits for any period of time because of ozone's reactive nature. The inability of ozone to provide a residual in the distribution system is a major drawback to its use. However, recent information about the formation of trihalomethanes by chlorine compounds has resulted in renewed interest in ozone as an alternative means of disinfection.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.2A List the physical agents that have been used for disinfection other than chlorine.

7.2B List the chemical agents that have been used for disinfection other than chlorine.

7.2C What is a major limitation to the use of ozone?

7.22 Chlorine (Cl_2)

7.220 Properties of Chlorine

Chlorine is a greenish-yellow gas with a penetrating and distinctive odor. The gas is two-and-a-half times heavier than air. Chlorine has a very high coefficient of expansion. If there is a temperature increase of 50°F (28°C) (from 35°F to 85°F or 2°C to 30°C), the volume will increase from 84 to 89 percent. This expansion could easily rupture a cylinder or line full of liquid chlorine. For this reason all chlorine containers must not be filled to more than 85 percent of their volume. One liter of liquid chlorine can evaporate and produce 450 liters of chlorine gas.

Chlorine by itself is non-flammable and non-explosive, but it will support combustion. When the temperature rises, so does the vapor pressure of chlorine. This means that when the temperature increases, the pressure of the chlorine gas inside a chlorine container will increase. This property of chlorine must be considered when:

1. Feeding chlorine gas from a container, and
2. Dealing with a leaking chlorine cylinder.

7.221 Chlorine Disinfection Action

The exact mechanism of chlorine disinfection action is not fully known. One theory holds that chlorine exerts a direct action against the bacterial cell, thus destroying it. Another theory is that the toxic character of chlorine inactivates the *ENZYMES*[6] which enable living microorganisms to use their food supply. As a result, the organisms die of starvation. From the point of view of water treatment, the exact mechanism of chlorine disinfection is less important than its demonstrated effects as a disinfectant.

When chlorine is added to water, several chemical reactions take place. Some involve the molecules of the water itself, and some involve organic and inorganic substances suspended in the water. We will discuss these chemical reactions in more detail in the next few sections of this chapter. First, however, there are some terms associated with chlorine disinfection that you should understand.

When chlorine is added to water containing organic and inorganic materials, it will combine with these materials and form chlorine compounds. If you continue to add chlorine, you will eventually reach a point where the reaction with organic and inorganic materials stops. At this point, you have satisfied what is known as the *"CHLORINE DEMAND."*

The chemical reactions between chlorine and these organic and inorganic substances produce chlorine compounds. Some of these compounds have disinfecting properties; others do not. In a similar fashion, chlorine reacts with the water itself and produces some substances with disinfecting properties. The total of all the compounds with disinfecting properties *PLUS* any remaining free (uncombined) chlorine is known as the *"CHLORINE RESIDUAL."* The presence of this measurable chlorine residual is what indicates to the operator that all possible chemical reactions have taken place and that there is still sufficient *"AVAILABLE RESIDUAL CHLORINE"* to kill the microorganisms present in the water supply.

Now, if you add together the amount of chlorine needed to satisfy the chlorine demand and the amount of chlorine residual needed for disinfection, you will have the *"CHLORINE DOSE."* This is the amount of chlorine you will have to add to the water to disinfect it.

$$\text{Chlorine Dose, mg/}L = \text{Chlorine Demand, mg/}L + \text{Chlorine Residual, mg/}L$$

where

$$\text{Chlorine Residual, mg/}L = \text{Combined Chlorine Forms, mg/}L + \text{Free Chlorine, mg/}L$$

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[6] *Enzymes (En-zimes). Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.*

7.222 Reaction with Water (HYDROLYSIS[7])

Free chlorine combines with water to form hypochlorous and hydrochloric acids:

$$\text{Chlorine} + \text{Water} \rightleftharpoons \text{Hypochlorous Acid} + \text{Hydrochloric Acid}$$

$$Cl_2 + H_2O \rightleftharpoons HOCl + HCl$$

Depending on the pH, hypochlorous acid may be present in the water as the hydrogen ion and hypochlorite ion (Figure 7.1).

$$\text{Hypochlorous Acid} \rightleftharpoons \text{Hydrogen Ion} + \text{Hypochlorite Ion}$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

In solutions that are dilute (low concentration of chlorine) and have a pH above 4, the formation of HOCl (hypochlorous acid) is most complete and leaves little free chlorine (Cl_2) existing. The hypochlorous acid is a weak acid and hence is poorly dissociated (broken up into ions) at pH levels below 6. Thus any free chlorine or hypochlorite (OCl^-) added to water will immediately form either HOCl or OCl^-, the species formed is thereby controlled by the pH value of the water. This is extremely important since HOCl and OCl^- differ in disinfection ability. HOCl has a much greater disinfection potential than OCl^-. Normally in water with a pH of 7.3, 50 percent of the chlorine present will be in the form of HOCl and 50 percent in the form of OCl^-. The higher the pH level, the greater the percent of OCl^-.

7.223 Reaction with Impurities in Water

Most waters that have been processed still contain some impurities. In this section we will discuss some of the more common impurities that react with chlorine and we will examine the effects of these reactions on the disinfection ability of chlorine.

A. Hydrogen sulfide (H_2S) and ammonia (NH_3) are two inorganic substances that may be found in water when it reaches the disinfection stage of treatment. Their presence can complicate the use of chlorine for disinfection purposes. This is because hydrogen sulfide and ammonia are what is known as *REDUCING AGENTS*. That is, they give up electrons easily. Chlorine reacts rapidly with these particular reducing agents producing some undesirable results.

Hydrogen sulfide produces an odor which smells like rotten eggs. It reacts with chlorine to form sulfuric acid and elemental sulfur (depending on temperature, pH and hydrogen sulfide concentration). Elemental sulfur is objectionable because it can cause odor problems and will precipitate as finely divided white particles which are sometimes colloidal in nature.

The chemical reactions between hydrogen sulfide and chlorine are as follows:

$$\text{Hydrogen Sulfide} + \text{Chlorine} + \text{Oxygen Ion} \rightarrow \text{Elemental Sulfur} + \text{Water} + \text{Chloride Ions}$$

$$H_2S + Cl_2 + O^{2-} \rightarrow S\downarrow + H_2O + 2\,Cl^-$$

The chlorine required to oxidize hydrogen sulfide to sulfur and water is 2.08 mg/*L* chlorine to 1 mg/*L* hydrogen sulfide. The complete oxidation of hydrogen sulfide to the sulfate form is as follows:

$$\text{Hydrogen Sulfide} + \text{Chlorine} + \text{Water} \rightarrow \text{Sulfuric Acid} + \text{Hydrochloric Acid}$$

$$H_2S + Cl_2 + 4\,H_2O \rightarrow H_2SO_4 + HCl$$

Thus, 8.32 mg/*L* of chlorine are required to oxidize one mg/*L* of hydrogen sulfide to the sulfate form. Note that in both reactions the chlorine is converted to the chloride ion (Cl^- or HCl) which has no disinfecting power nor produces any chlorine residual. In waterworks practice we always chlorinate to produce a chlorine residual, therefore the second reaction (complete oxidation of hydrogen sulfide) occurs before we have any chlorine residual in the water we are treating.

When chlorine is added to water containing ammonia (NH_3), it reacts rapidly with the ammonia and forms *CHLORAMINES*[8]. This means that less chlorine is available to act as a disinfectant. As the concentration of ammonia increases, the disinfectant power of the chlorine drops off at a rapid rate.

B. When organic materials are present in water being disinfected with chlorine, the chemical reactions that take place may produce suspected carcinogenic compounds (trihalomethanes). The formation of these compounds can be prevented by limiting the amount of prechlorination and by removing the organic materials prior to chlorination of the water.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.2D List two inorganic reducing chemicals that react rapidly with chlorine.

7.2E How is the chlorine demand determined?

7.2F How is the chlorine dosage determined?

7.23 Hypochlorite (OCl^-)

7.230 Reactions with Water

The use of hypochlorite to treat potable water achieves the same result as chlorine gas. Hypochlorite may be applied in the form of calcium hypochlorite ($Ca(OCl)_2$) or sodium hypochlorite (NaOCl). The form of calcium hypochlorite most frequently used to disinfect water is known as **High Test Hypochlorite** (*HTH*). The chemical reactions of hypochlorite in water are similar to those of chlorine gas.

CALCIUM HYPOCHLORITE

$$\text{Calcium Hypochlorite} + \text{Water} \rightarrow \text{Hypochlorous Acid} + \text{Calcium Hydroxide}$$

$$Ca(OCl)_2 + 2\,H_2O \rightarrow 2\,HOCl + Ca(OH)_2$$

SODIUM HYPOCHLORITE

$$\text{Sodium Hypochlorite} + \text{Water} \rightarrow \text{Hypochlorous Acid} + \text{Sodium Hydroxide}$$

$$NaOCl + H_2O \rightarrow HOCl + Na(OH)$$

Calcium hypochlorite (HTH) is used by a number of small water supply systems. A problem occurs in these systems when sodium fluoride is injected at the same point as the

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[7] *Hydrolysis (hi-DROLL-uh-sis). A chemical reaction in which a compound is converted into another compound by taking up water.*

[8] *Chloramines (KLOR-uh-means). Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.*

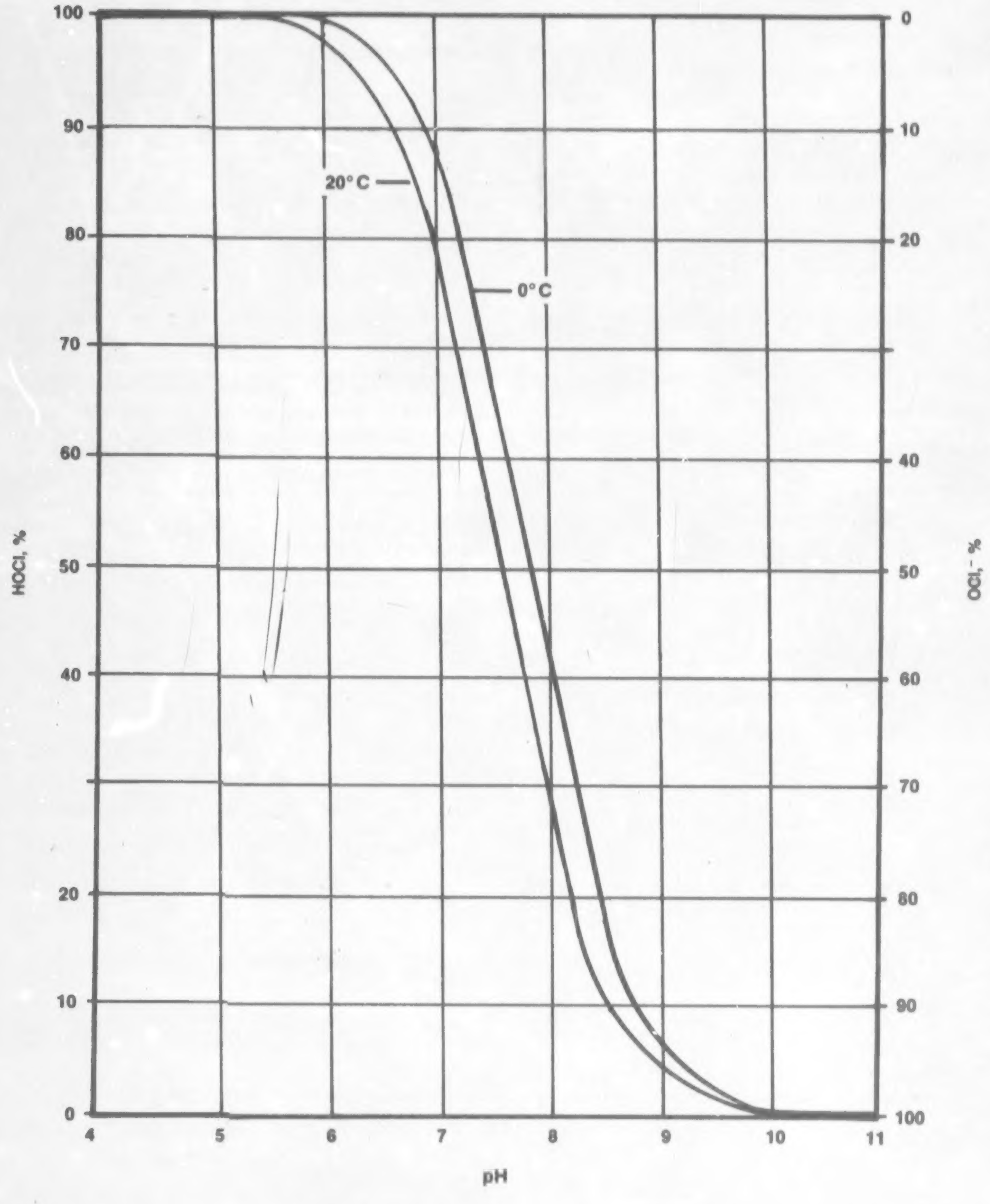


Fig. 7.1 Relationship between hypochlorous acid (HOCl), hypochlorite ion (OCl^-) and pH

hypochlorite. A severe crust is formed when the calcium and fluoride ions combine.

7.231 *Differences Between Chlorine Gas and Hypochlorite Compound Reactions*

The only difference between the reactions of the hypochlorite compounds and chlorine gas is the "side" reactions of the end products. The reaction of chlorine gas tends to lower the pH (increases the hydrogen ion (H^+) concentration) by the formation of hydrochloric acid which favors the formation of hypochlorous acid (HOCl). The hypochlorite tends to raise the pH with the formation of hydroxyl ions (OH^-) from the calcium or sodium hydroxide. At a high pH of around 8.5 or higher, the hypochlorous acid (HOCl) is almost completely dissociated to the ineffective hypochlorite ion (OCl^-) (Figure 7.1). This reaction also depends on the *BUFFER CAPACITY*[9] (amount of bicarbonate, HCO_3^-, present) of the water.

$$\underset{\text{Acid}}{\text{Hypochlorous}} \rightleftharpoons \underset{\text{Ion}}{\text{Hydrogen}} + \underset{\text{Ion}}{\text{Hypochlorite}}$$

$$HOCl \rightleftharpoons H^+ + OCl^-$$

7.24 Chlorine Dioxide (ClO_2)

7.240 *Reaction in Water*

Chlorine dioxide may be used as a disinfectant. Chlorine dioxide does not form carcinogenic compounds that may be formed by other chlorine compounds. Also it is not affected by ammonia, and is a very effective disinfectant at higher pH levels. In addition, chlorine dioxide reacts with sulfide compounds, thus helping to remove them and eliminate their characteristic odors. Phenolic tastes and odors can be controlled by using chlorine dioxide.

Chlorine dioxide reacts with water to form chlorate and chlorite ions in the following manner:

$$\underset{\text{Dioxide}}{\text{Chlorine}} + \text{Water} \rightarrow \underset{\text{Ion}}{\text{Chlorate}} + \underset{\text{Ion}}{\text{Chlorite}} + \underset{\text{Ions}}{\text{Hydrogen}}$$

$$2\ ClO_2 + H_2O \rightarrow ClO_3^- + ClO_2^- + 2\ H^+$$

7.241 *Reactions with Impurities in Water*

A. *INORGANIC COMPOUNDS*
Chlorine dioxide is an effective *OXIDIZING AGENT*[10] with iron and manganese and does not leave objectionable tastes or odors in the finished water. Because of its oxidizing ability, chlorine dioxide usage must be monitored and the dosage will have to be increased when treating waters with iron and manganese.

B. *ORGANIC COMPOUNDS*
Chlorine dioxide does not react with organics in water. Therefore, there is little danger of the formation of potentially dangerous trihalomethanes.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.2G How does pH influence the relationship between HOCl and OCl^-?

7.2H How does chlorine gas and hypochlorite influence pH?

7.25 Breakpoint Chlorination[11]

In determining how much chlorine you will need for disinfection, remember you will be attempting to produce a certain chlorine residual in the form of *FREE AVAILABLE RESIDUAL CHLORINE*[12]. Chlorine in this form has the highest disinfecting ability. *BREAKPOINT CHLORINATION* is the name of this process of adding chlorine to water until the chlorine demand has been satisfied. Further additions of chlorine will result in a chlorine residual that is directly proportional to the amount of chlorine added beyond the breakpoint. Public water supplies are normally chlorinated *PAST THE BREAKPOINT.*

Take a moment here to look at the breakpoint chlorination curve in Figure 7.2. Assume the water being chlorinated contains some manganese, iron, nitrate, organic matter and ammonia. Now add a small amount of chlorine. The chlorine reacts with (oxidizes) the manganese, iron and nitrite. That's all that happens — no disinfection and no chlorine residual (Figure 7.2, points 1 to 2). Add a little more chlorine, enough to react with the organics and ammonia; *CHLORORGANICS*[13] and *CHLORAMINES*[14] will form. The chloramines produce a combined chlorine residual — a chlorine residual combined with other substances so it has lost some of its disinfecting strength. Combined residuals have rather poor disinfecting power and may cause tastes and odors (points 1 to 3).

With just a little more chlorine the chloramines and some of the chlororganics are destroyed (points 3 to 4). Adding just one last amount of chlorine we get *FREE AVAILABLE RESIDUAL CHLORINE* (beyond point 4) — free in the sense that it has not reacted with anything and available in that it *CAN* and *WILL* react if need be. Free available residual chlorine is the best residual for disinfection. It disinfects faster and without the "swimming pool" odor of combined residual chlorine. Free available residual chlorine begins to form at the breakpoint; the process is called *BREAKPOINT CHLORINATION.* In water treatment plants today it is common practice to go "past the breakpoint." This means that the treated water will have a low chlorine residual, but the residual will be a very effective disinfectant because it is in the form of *FREE AVAILABLE RESIDUAL CHLORINE.*

Let's look more closely at some of the chemical reactions that take place during chlorination. When chlorine is added to waters containing ammonia (NH_3), the ammonia reacts

---

[9] *Buffer Capacity. A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.*

[10] *Oxidizing Agent. Any substance, such as oxygen (O_2) and chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a reducing agent.*

[11] *Breakpoint Chlorination. The addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.*

[12] *Free Available Residual Chlorine. That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.*

[13] *Chlororganic (chlor-or-GAN-nick). Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.*

[14] *Chloramines (KLOR-uh-means). Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.*

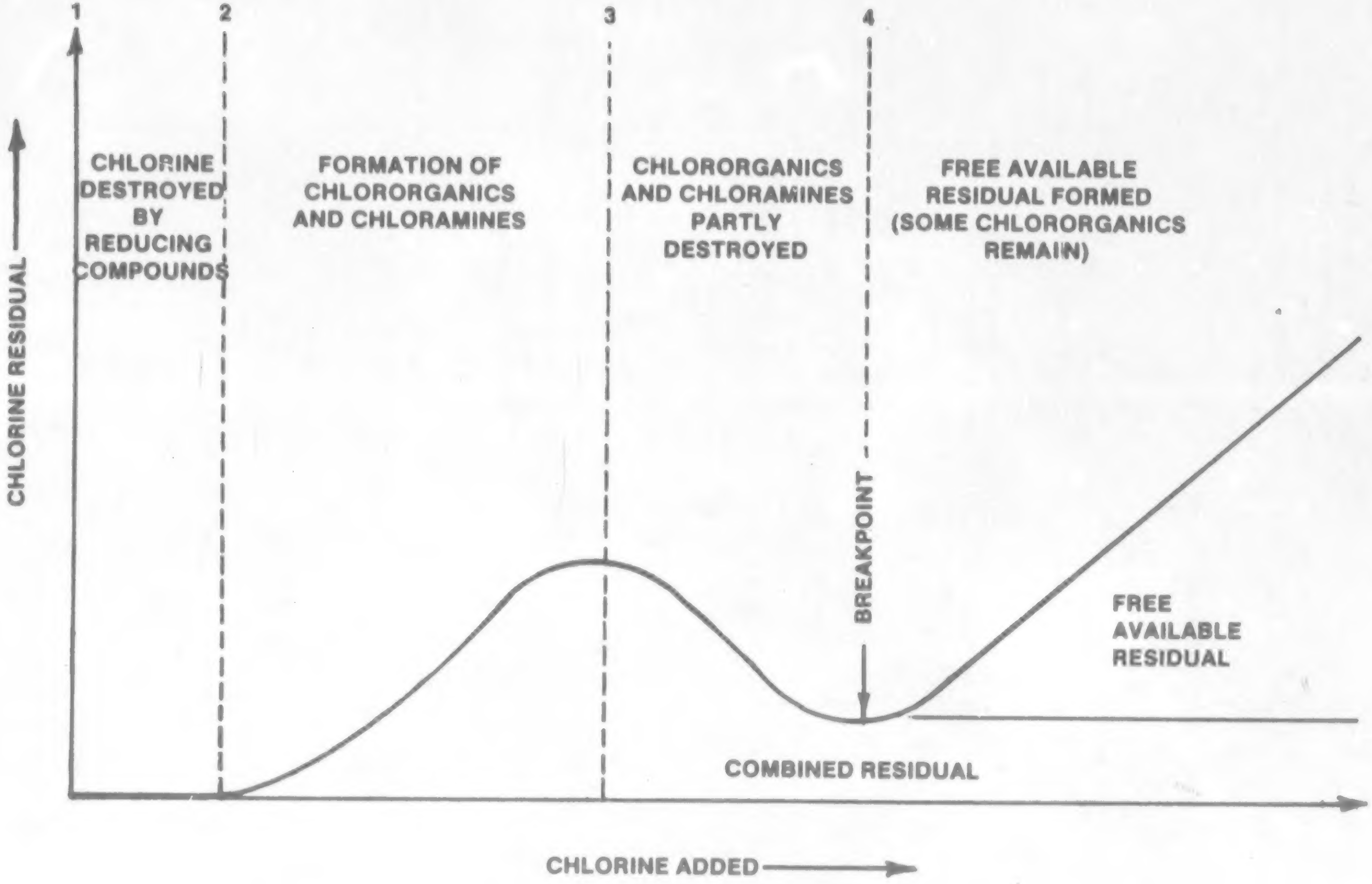
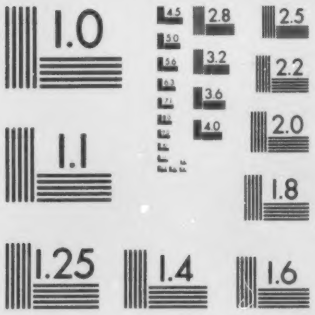


Fig. 7.2 Breakpoint chlorination curve

25


1.0
4.5
5.0
5.6
6.3
7.1
8.0
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS
STANDARD REFERENCE MATERIAL 1010a
(ANSI and ISO TEST CHART No. 2)

with hypochlorous acid (HOCl) to form monochloramine, dichloramine and trichloramine. The formation of these chloramines depends on the pH of the solution and the initial chlorine-ammonia ratio.

Ammonia + Hypochlorous Acid → Chloramine + Water

$NH_3 + HOCl \rightarrow NH_2Cl + H_2O$ Monochloramine

$NH_2Cl + HOCl \rightarrow NHCl_2 + H_2O$ Dichloramine

$NHCl_2 + HOCl \rightarrow NCl_3 + H_2O$ Trichloramine[15]

At the pH levels that are usually found in water (pH 6.5 to 7.5), monochloramine and dichloramine exist together. At pH levels below 5.5, dichloramine exists by itself. Below pH 4.0, trichloramine is the only compound found. The mono- and dichloramine forms have definite disinfection powers and are of interest in the measurement of chlorine residuals. Dichloramine has a more effective disinfecting power than monochloramine. However, dichloramine is not recommended as a disinfectant because of taste and odor problems. Chlorine reacts with *PHENOL*[16] and salicylic acid (both are leached into water from leaves and blossoms) to form *CHLOROPHENOL*[17] which has an intense medicinal odor. This reaction goes much slower in the presence of monochloramine.

Historically some plants add ammonia (aqua ammonia) to the filter effluent when they chlorinated (postchlorination) to produce chloramines. The reason for this practice was that chloramines produced very long lasting chlorine residuals. Today plants are considering adding ammonia because chloramines do not form trihalomethanes. A major limitation of using chloramine residuals is the fact that chloramines are not as effective as a disinfectant as free chlorine residuals. Another potential problem is that chloramines may cause tastes and odors in the treated water. Studies have indicated a dosage of three parts chlorine to one part ammonia (3:1) will form monochloramines. Monochloramines form combined residual chlorine (rising part of breakpoint curve in Figure 7.2) and apparently do not produce tastes and odors. Dichloramines form during the oxidation of combined residual materials (Figure 7.2) and will cause tastes and odors. Trichloramines are formed past the breakpoint and also may form tastes and odors. Although chloramines are non-toxic to healthy humans, they can have a debilitating (weakening) effect on individuals with renal disease and who must undergo kidney dialysis.

In plants where triahalomethanes (THMs) are not a problem, sufficient chlorine is added to the raw water (prechlorination) to go "past the breakpoint." The chlorine residual will aid coagulation, control algae problems in basins, reduce odor problems in treated water, and provide sufficient chlorine contact time for an effective kill of pathogenic organisms. Therefore the treated water will have a very low chlorine residual, but the residual will be a very effective disinfectant.

7.26 Critical Factors

Both *CHLORINE RESIDUAL* and *CONTACT TIME* are essential for effective killing of pathogenic microorganisms. Complete initial mixing is very important. Changes in pH affect the disinfection ability of chlorine and you must reexamine the best combination of contact time and chlorine residual when the pH fluctuates. Critical factors influencing disinfection are summarized as follows:

1. Injection point and method of mixing to get disinfectant in contact with water being disinfected. Depends on whether using prechlorination or postchlorination.
2. Contact time. With good initial mixing, the longer the contact time, the better the disinfection.
3. Effectiveness of upstream treatment processes. The lower the turbidity (suspended solids, organic content, reducing agents) of the water, the better the disinfection.
4. Temperature. The higher the temperature, the more rapid the rate of disinfection.
5. Dosage and type of chemical. Usually the higher the dosage, the quicker the disinfection rate. The form (chloramines or free chlorine residual) and type of chemical also influences the disinfection rate.
6. pH. The lower the pH, the better the disinfection.

7.27 Process Calculations

FORMULAS

There are two basic chlorination process calculations:

1. Chlorine dosage, mg/*L*, and
2. Chlorine demand, mg/*L*.

To calculate the chlorine dosage (dose) of the water being treated, we need to know the chlorine fed to the water being treated in pounds of chlorine per day and the amount of water treated in million gallons per day. With this information we can calculate the chlorine dosage in milligrams of chlorine per liter of water. Let's recall our basic chemical feed formula,

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal}).$$

This formula can be rearranged using Davidson's Pie Method (see Appendix, Section A.12, "How to Use the Basic Formulas").

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chemical Feed, lbs/day}}{(\text{Flow, MGD})(8.34\ \text{lbs/gal})}$$

---

[15] *More commonly called nitrogen trichloride.*

[16] *Phenol (FEE-noll). Organic compounds that are derivatives of benzene.*

[17] *Chlorophenol (klor-o-FEE-noll). Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.*

When we determine the chlorine dose in milligrams of chlorine per liter for the water we are treating, we must add enough chlorine to the water to meet the chlorine demand and the desired chlorine residual.

$$\text{Chlorine Dose, mg}/L = \text{Chlorine Demand, mg}/L + \text{Chlorine Residual, mg}/L$$

If we wish to know the chlorine demand, then we rearrange the terms by subtracting the chlorine residual from the chlorine dose.

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L$$

EXAMPLE 1

A chlorinator is set to feed 20 pounds of chlorine in 24 hours to a flow of 0.85 MGD. Find the chlorine dose in mg/*L*.

Known		Unknown
Chlorinator Setting, lbs/24 hrs	= 20 lbs Cl/24 hrs	Chlorine Dose, mg/*L*
Flow, MGD	= 0.85 MGD	

Calculate the chlorine dose in mg/*L*.

$$\begin{aligned}\text{Chlorine Dose, mg}/L &= \frac{\text{Chlorine Feed, lbs/day}}{(\text{Water Treated, Million gal/day})\ (8.34\ \text{lbs/gal})}\\ &= \frac{20\ \text{lbs Cl/day}}{(0.85\ \text{Million gal/day})\ (8.34\ \text{lbs/gal})}\\ &= \frac{20\ \text{lbs Cl/day}}{7.1\ \text{Million lbs Water/day}}\\ &= 2.8\ \text{lbs chlorine/million lbs water}\\ &= 2.8\ \text{ppm (Parts Per Million parts)}\\ &= 2.8\ \text{mg}/L\end{aligned}$$

EXAMPLE 2

Find the chlorine demand in mg/*L* for the water being treated in Example 1 with a chlorine dose of 2.8 mg/*L*. The chlorine residual after 30 minutes of contact time is 0.5 mg/*L*.

Known		Unknown
Chlorine Dose, mg/*L*	= 2.8 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L*	= 0.5 mg/*L*	

Find the chlorine demand in mg/*L*.

$$\begin{aligned}\text{Chlorine Demand, mg}/L &= \text{Chlorine Dose, mg}/L = \text{Chlorine Residual, mg}/L\\ &= 2.8\ \text{mg}/L - 0.5\ \text{mg}/L\\ &= 2.3\ \text{mg}/L\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.2I What does chlorine produce when it reacts with organic matter?

7.2J What is breakpoint chlorination?

7.3 POINTS OF CHLORINE APPLICATION (Figure 7.3)

7.30 Prechlorination

Prechlorination is the application of chlorine ahead of any other treatment processes. While prechlorination may increase the formation of trihalomethanes in raw water containing organic *PRECURSOR*[18] (THM) compounds and tastes and odors when phenolic compounds are present, it provides the following benefits:

1. Control of algae and slime growths,
2. Control of mud ball formation,
3. Improved coagulation,
4. Reduction of tastes and odors,
5. Increased chlorine contact time, and
6. Increased safety factor in disinfection of heavily contaminated waters.

7.31 Postchlorination

Postchlorination is the application of chlorine after the water has been treated but before it enters the distribution system. This is the primary point of disinfection and it is normally the last application of any disinfectant.

7.32 Rechlorination

Rechlorination is the practice of adding chlorine in the distribution system. This practice is common when the distribution system is long or complex. The application point could be any place where adequate mixing is available.

7.33 Wells

Chlorination of wells is required in some areas and is a good practice whenever wells are used for public water supplies. This is usually accomplished with a small system and can be automated for ease of operation.

7.34 Mains

Mains are usually not a problem and are not chlorinated except in long pipelines and in complex systems. Mains must be chlorinated after initial installation and any repairs.

7.35 Tanks and Reservoirs

Usually tanks and reservoirs are not chlorinated unless specific problems develop which cannot be solved by other means. Tanks must be chlorinated after initial installation, repairs, maintenance, repainting and cleaning. In other words, anytime a tank has been drained or entered, it should be chlorinated.

7.36 Water Supply Systems

See *WATER SUPPLY SYSTEM OPERATION* (another manual in this series) for detailed procedures on how to disinfect wells, mains, tanks and reservoirs.

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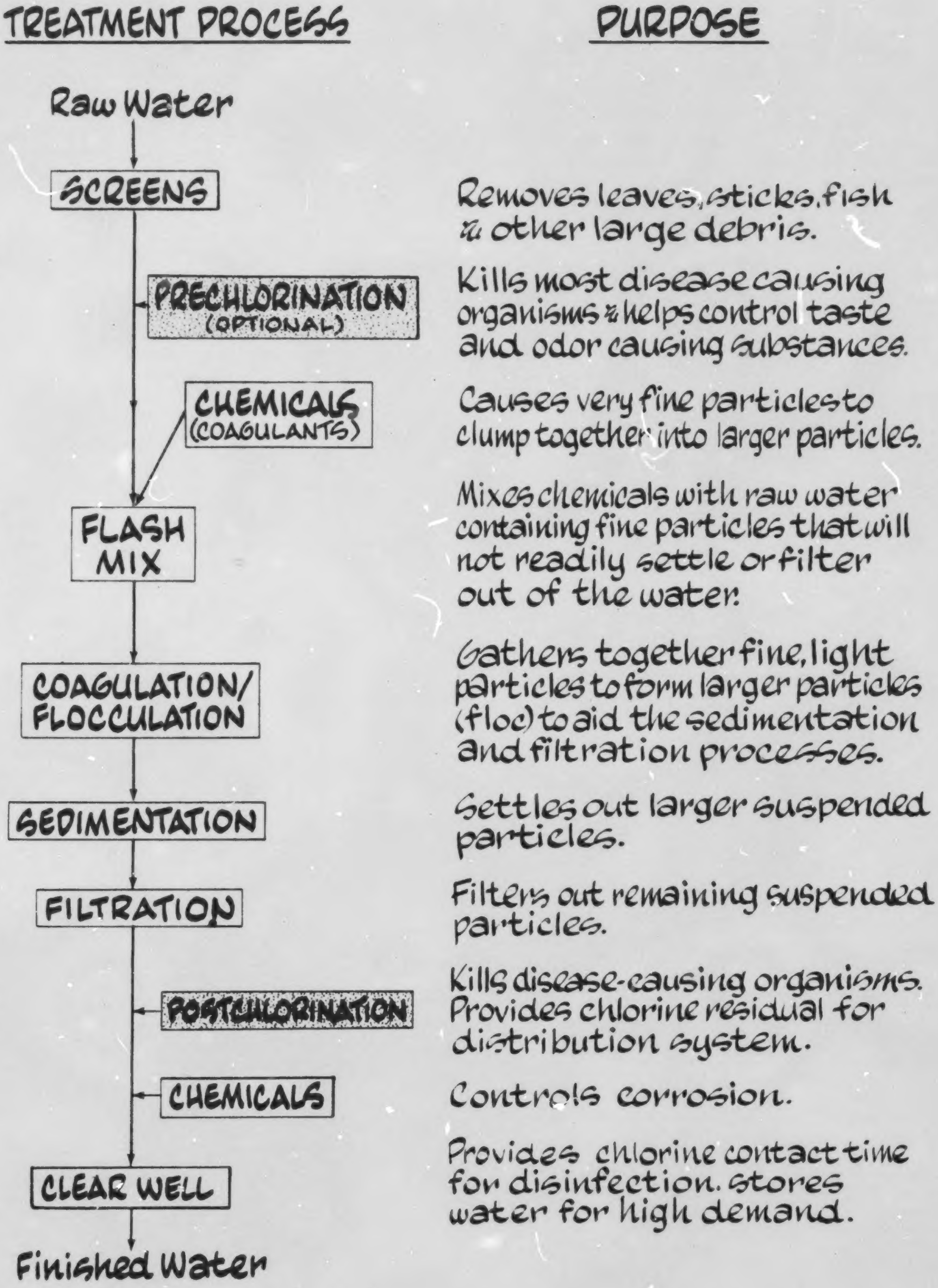
[18] *Precursor, THM (pre-CURSE-or). Natural organic compounds found in all surface and groundwaters. These compounds MAY react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they MUST be present in order for THMs to form.*



TREATMENT PROCESS	PURPOSE
Raw Water	
SCREENS	Removes leaves, sticks, fish & other large debris.
PRECHLORINATION (OPTIONAL)	Kills most disease causing organisms & helps control taste and odor causing substances.
CHEMICALS (COAGULANTS)	Causes very fine particles to clump together into larger particles.
FLASH MIX	Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water.
COAGULATION/ FLOCCULATION	Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration processes.
SEDIMENTATION	Settles out larger suspended particles.
FILTRATION	Filters out remaining suspended particles.
POSTCHLORINATION	Kills disease-causing organisms. Provides chlorine residual for distribution system.
CHEMICALS	Controls corrosion.
CLEAR WELL	Provides chlorine contact time for disinfection. Stores water for high demand.
Finished Water	

Fig. 7.3 Typical flow diagram for a water treatment plant

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.3A List the two most common points (locations) of chlorination in a water treatment plant.

7.3B What are the benefits of prechlorination?

7.3C Under what conditions should waters not be prechlorinated?

End of Lesson 1 of 3 Lessons
on
DISINFECTION

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. DISINFECTION

(Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter, you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. What is the difference between disinfection and sterilization?
2. How does organic matter in water influence disinfection?
3. How do physical and chemical methods accomplish disinfection?
4. Why is chlorine dioxide considered an effective disinfectant?
5. What are the benefits and limitations of prechlorination?

Chapter 7. DISINFECTION

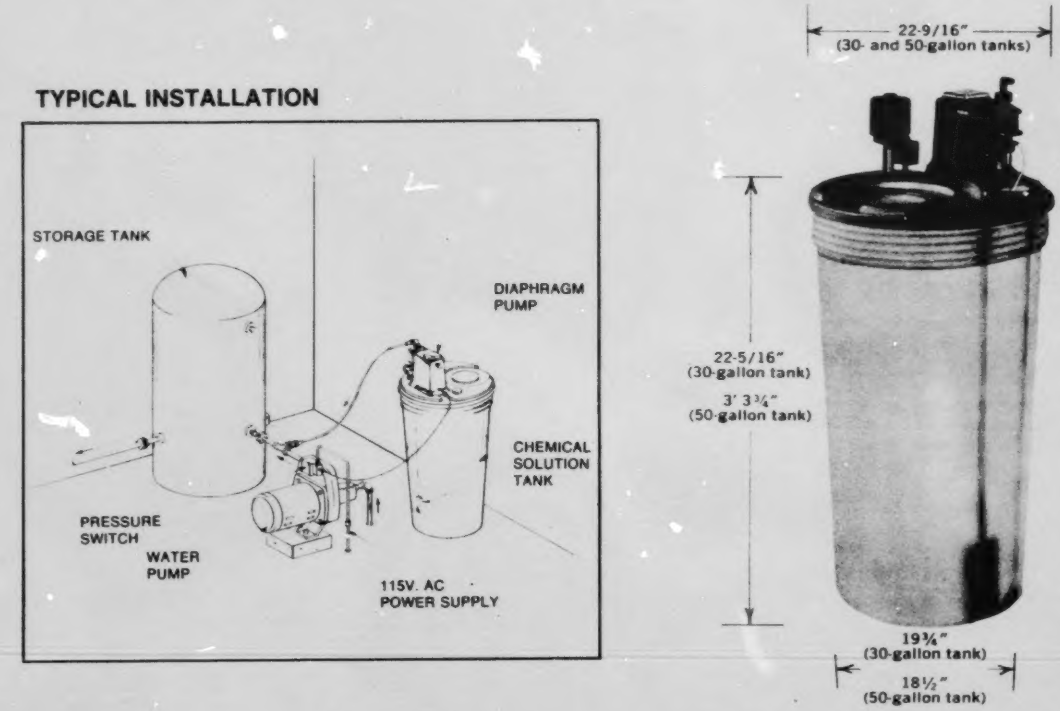
(Lesson 2 of 3 Lessons)

7.4 OPERATION OF CHLORINATION EQUIPMENT

7.40 Hypochlorinators

Hypochlorinators used on small water systems are very simple and relatively easy to install. Typical installations are shown in Figures 7.4 and 7.5. Hypochlorinator systems usually consist of a chemical solution tank for the hypochlorite, diaphragm-type pump (Figure 7.6), power supply, water pump, pressure switch and water storage tank.

There are two methods of feeding the hypochlorite solution into the water being disinfected. The hypochlorite solution may be pumped directly into the water (Figure 7.7). In the other method, the hypochlorite solution is pumped through an *EDUCTOR*[19] or injector which draws in additional water for dilution of the hypochlorite solution (Figure 7.8).


TYPICAL INSTALLATION
STORAGE TANK
DIAPHRAGM PUMP
CHEMICAL SOLUTION TANK
PRESSURE SWITCH
WATER PUMP
115V. AC POWER SUPPLY
22-9/16" (30- and 50-gallon tanks)
22-5/16" (30-gallon tank)
3' 3¾" (50-gallon tank)
19¾" (30-gallon tank)
18½" (50-gallon tank)

Pump-tank system for chemical mixing and metering. Cover supports pump, impeller-type mixer, and liquid-level switch.

Fig. 7.4 Typical hypochlorinator installation

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

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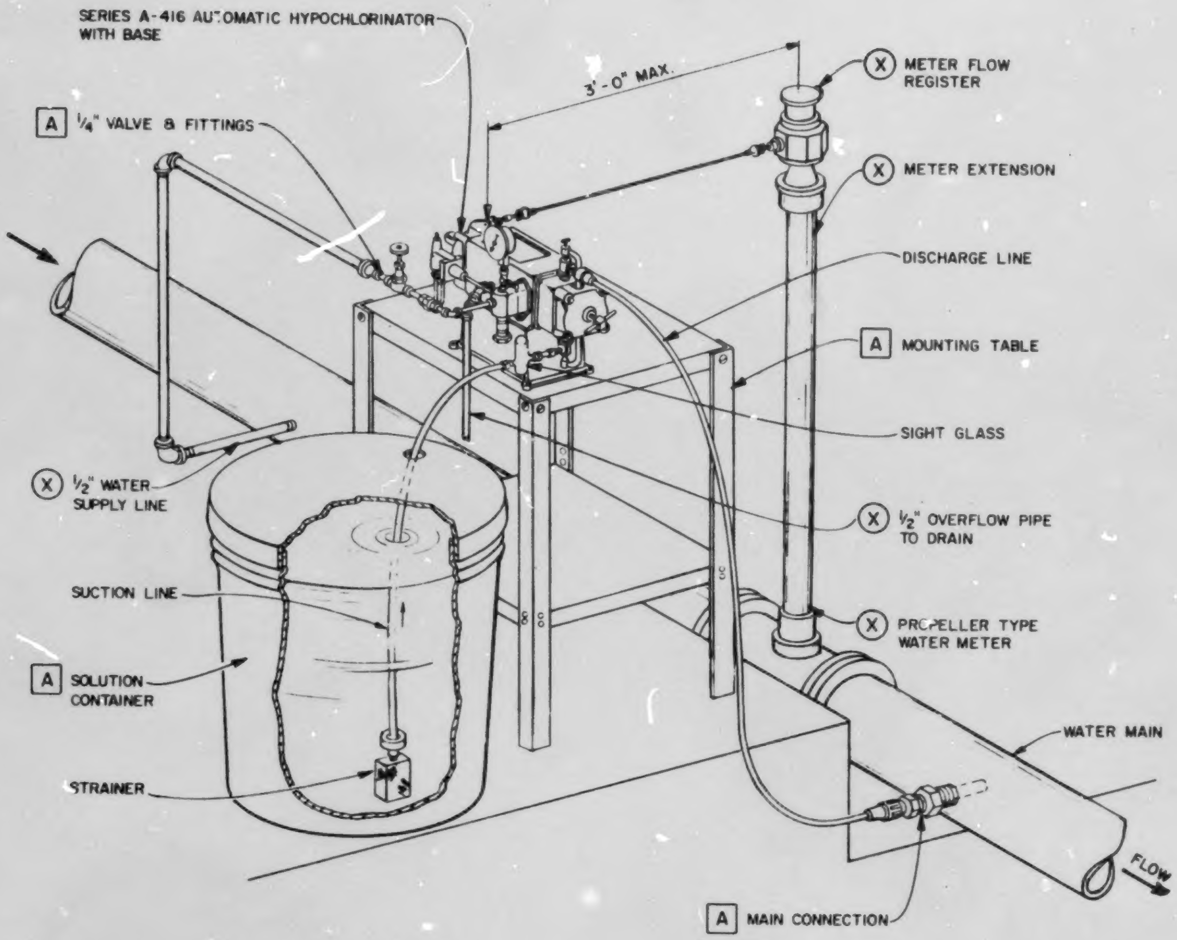
[19] *Eductor (e-DUCK-tor). A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction such as a Venturi.*


SERIES A-416 AUTOMATIC HYPOCHLORINATOR WITH BASE
A ¼" VALVE & FITTINGS
3'-0" MAX.
Ⓧ METER FLOW REGISTER
Ⓧ METER EXTENSION
DISCHARGE LINE
A MOUNTING TABLE
SIGHT GLASS
Ⓧ ½" WATER SUPPLY LINE
Ⓧ ½" OVERFLOW PIPE TO DRAIN
SUCTION LINE
Ⓧ PROPELLER TYPE WATER METER
A SOLUTION CONTAINER
WATER MAIN
STRAINER
FLOW
A MAIN CONNECTION

Ⓧ *NOT FURNISHED BY W & T.*

A *ACCESSORY ITEM FURNISHED ONLY IF SPECIFICALLY LISTED IN QUOTATION AND AS CHECKED ON THIS DRAWING.*

NOTE: Hypochlorinator paced by a propeller-type water meter.

Fig. 7.5 Typical hypochlorinator installation
(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

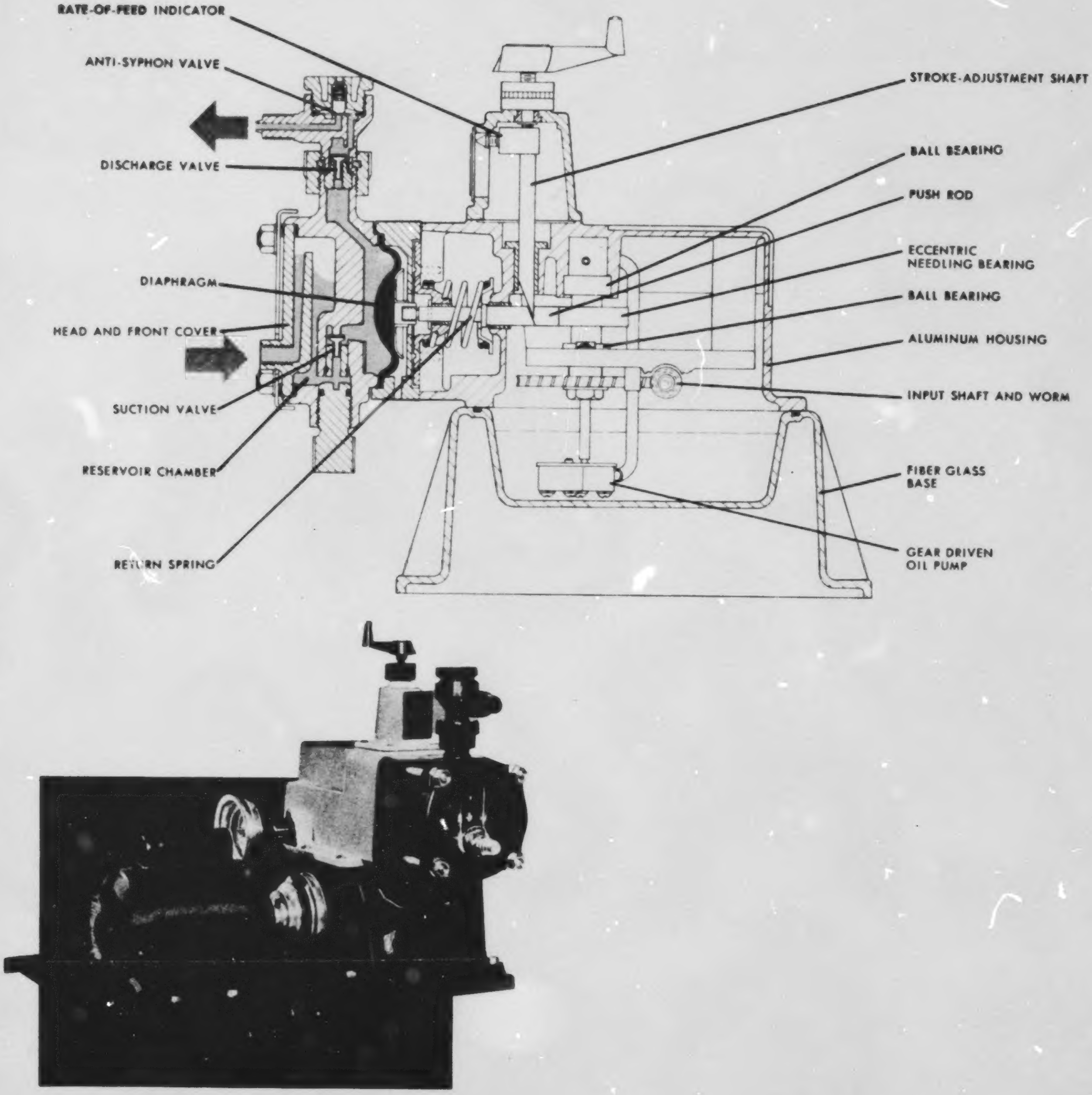

RATE-OF-FEED INDICATOR
ANTI-SYPHON VALVE
DISCHARGE VALVE
DIAPHRAGM
HEAD AND FRONT COVER
SUCTION VALVE
RESERVOIR CHAMBER
RETURN SPRING
STROKE-ADJUSTMENT SHAFT
BALL BEARING
PUSH ROD
ECCENTRIC NEEDLING BEARING
BALL BEARING
ALUMINUM HOUSING
INPUT SHAFT AND WORM
FIBER GLASS BASE
GEAR DRIVEN OIL PUMP

Fig. 7.6 Diaphragm-type pump

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

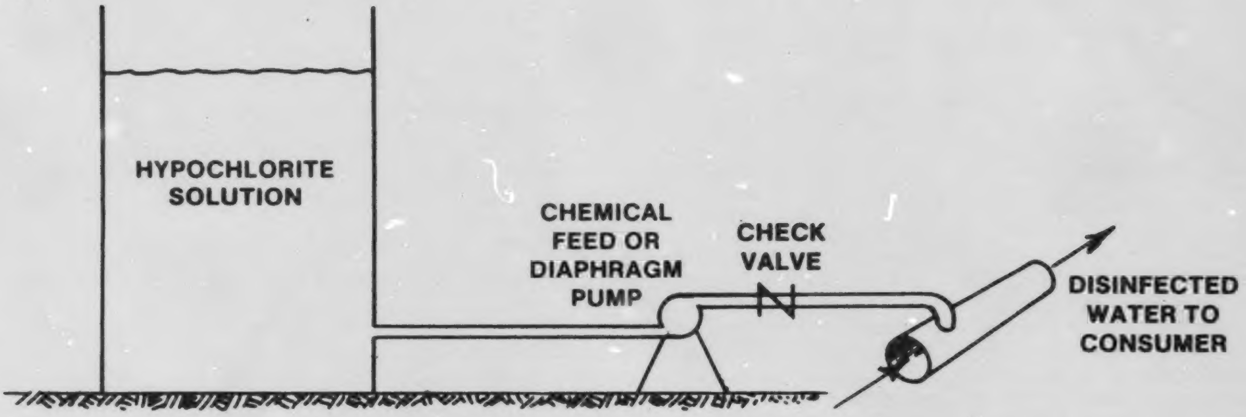
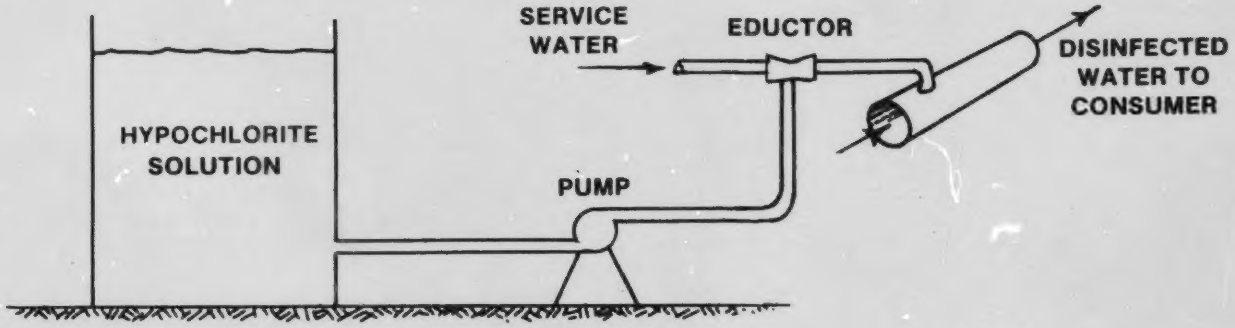

HYPOCHLORITE SOLUTION
CHEMICAL FEED OR DIAPHRAGM PUMP
CHECK VALVE
DISINFECTED WATER TO CONSUMER

Fig. 7.7 Hypochlorinator direct pumping system


SERVICE WATER
EDUCTOR
DISINFECTED WATER TO CONSUMER
HYPOCHLORITE SOLUTION
PUMP

NOTE: Pump is chemical feed or diaphragm pump

Fig. 7.8 Hypochlorinator injector feed system

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.4A List the major parts of a typical hypochlorinator system.

7.4B What are the two common methods of feeding hypochlorite to the water being disinfected?

7.41 Chlorinators

A typical chlorine installation is shown in Figure 7.9. The figure shows the exhaust fan installed at floor level. A potential problem for this type of installation is that any chlorine drawn through the fan could corrode the wiring in the fan or the controls and cause a failure of the ventilation system. We recommend that fans be used which draw air from the roof and push air and any chlorine out the floor vents. Chlorine gas may be removed from chlorine containers by a valve and piping arrangement to the chlorinators (Figure 7.9). In many smaller systems chlorine gas is withdrawn with equipment installed directly on the cylinder (Figures 7.10, 7.11 and 7.12).

Chlorine may be delivered by vacuum-controlled solution-feed chlorinators (Figures 7.9, 7.13 and 7.14). The chlorine gas is controlled, metered, introduced into a stream of *INJECTOR WATER*[20], and then conducted as a solution to the point of application.

A typical vacuum-controlled chlorinator is shown in Figures 7.13 and 7.14 and the purpose of the parts are listed in Table 7.4. Chlorine gas flows from a chlorine container to the gas inlet (see Figure 7.14). After entering the chlorinator, the gas passes through a spring-loaded pressure regulating valve which maintains the proper operating pressure. A *ROTAMETER*[21] is used to indicate the rate of gas flow. The rate is controlled by an orifice. The gas then moves to the injector where it is dissolved in water. This mixture leaves the chlorinator as a chlorine solution (HOCl) ready for application.

The operating vacuum is provided by a hydraulic injector. The water supplied by this injector absorbs the chlorine gas. The resulting chlorine solution is conveyed to a chlorine diffuser through a corrosion-resistant conduit. A vacuum regulating valve dampens fluctuations and gives smoother operation. A vacuum relief prevents excessive vacuum within the equipment.

The primary advantage of vacuum operation is safety. If a failure or breakage occurs in the vacuum system, the chlorinator either stops the flow of chlorine into the equipment or allows air to enter the vacuum system rather than allowing chlorine to escape into the surrounding atmosphere. In case the chlorine inlet shutoff fails, a vent valve discharges the incoming gas to the outside of the chlorinator building.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.4C What is the primary advantage of vacuum system chlorinators?

7.4D How is the rate of gas flow in a chlorinator measured?

7.42 Chlorine Containers

7.420 Plastic (Figures 7.4 and 7.5)

Plastic containers are suitable for storage of hypochlorite solution. The container size depends on usage. Normally a week's supply of hypochlorite solution should be available.

7.421 Steel Cylinders (Figures 7.15 and 7.16)

Cylinders containing 100 to 150 pounds (45 to 68 kg) of chlorine are convenient for very small treatment plants with capacities of less than 0.5 MGD (1890 cu m/day). A fusible plug is placed in the valve below the valve seat (Figure 7.17). This plug is a safety device. The fusible metal softens or melts at 158° to 165°F (70° to 74°C) to prevent buildup of excessive pressures and the possibility of rupture due to a fire or high surrounding temperatures. Cylinders will not explode under normal conditions and can be handled safely.

The following are safe procedures for handling chlorine cylinders:

1. Move cylinders with a properly balanced hand truck (Figure 7.18) with clamp supports that fasten about two-thirds of the way up the cylinder.
2. 100 and 150 pound (45 to 68 kg) cylinders can be rolled in a vertical position. Avoid lifting these cylinders except with approved equipment. Never lift with homemade chain devices, rope slings, or magnetic hoists. Never roll, push or drop cylinders off the back of trucks or loading docks.
3. Always replace the protective cap when moving a cylinder.
4. Keep cylinders away from direct heat (steam pipes or radiators) and direct sun, especially in warm climates.
5. Transport and store cylinders in an upright position.
6. Firmly secure cylinders to an immovable object (Figure 7.16)

7.422 Ton Tanks (Figures 7.19 and 7.20)

Ton tanks are of welded steel construction and have a loaded weight of as much as 3700 pounds (1680 kg). They are about 80 inches (200 cm) in length and 30 inches (75 cm) in outside diameter. The ends of the tanks are crimped inward to provide a substantial grip for lifting clamps (Figure 7.21).

Most ton tanks have eight openings for fusible plugs and valves (Figures 7.21 and 7.22). Generally, two operating valves are located on one end near the center. There are six or eight fusible metal safety plugs, three or four on each end. These are designed to melt within the same temperature range as the safety plug in the cylinder valve.

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[20] *Injector Water. Service water in which chlorine is added (injected) to form a chlorine solution.*

[21] *Rotameter (RODE-uh-ME-ter). A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.*

TABLE 7.4 CHLORINATOR PARTS AND PURPOSES (Figures 7.13 and 7.14)

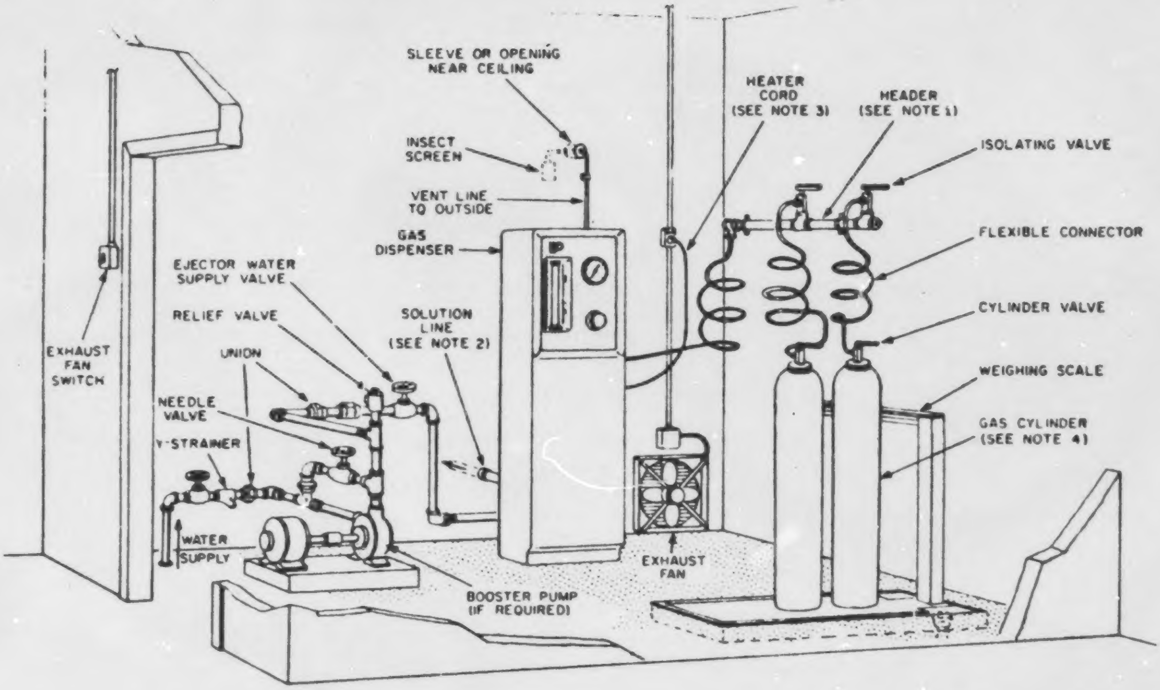
PART	PURPOSE
1. Pressure Gage (Not shown on Fig. 7.13)	Indicates chlorine gas pressure at chlorinator system from chlorine manifold and supply (20 psi minimum and 40 psi maximum or 137.9 kilo*PASCAL*[22] minimum and 275.8 kPa maximum).
2. Gas Supply	Provides source of chlorine gas from containers to chlorinator system.
3. Vacuum Regulator-Check Unit	Maintains a constant vacuum on chlorinator.
4. Standby Pressure Relief	Relieves excess gas pressure on chlorinator.
5. Vent	Discharges any excess chlorine gas (pressure) to atmosphere outside of chlorination building.
6. Gas Inlet	Allows entrance of chlorine gas to chlorinator. Gas flows from chlorine container through supply line and gas manifold to inlet.
7. Heater	Prevents *RELIQUEFACTION*[23] of chlorine gas.
8. Vacuum Gage	Indicates vacuum on chlorinator system.
9. Rotameter Tube and Float	Indicate chlorinator feed rate. (Read the widest part or top of the float or center of ball for rate marked on tube.)
10. Differential Regulating (Reducing) Valve	Regulates (reduces) chlorinator chlorine gas pressure. Serves to maintain a constant differential across the orifice in order to obtain repeatable chlorine gas flow rates at a given orifice opening regardless of fluctuations in the injector vacuum.
11. Plug and Variable Orifice	Control chlorine feed rate by regulating flow of chlorine gas.
12. Vacuum Relief Valve	Relieves excess vacuum by allowing air to enter system and reduce vacuum.
13. Vacuum Relief	Provides source of air to reduce excess vacuum.
14. Injector Vacuum Gage	Indicates vacuum at the injector.
15. Diaphragm Check-valve	Regulates chlorinator vacuum which in turn adjusts chlorinator feed rate. Receives signal from chlorine feed rate controls and then adjusts feed rate by regulating vacuum.
16. Manual Feed Rate Adjuster	Regulates chlorine feed rate manually. Most chlorination systems have automatic feed rate controls with a manual override.
17. Injector Water Supply	Provides source of water for chlorine solution. Must provide sufficient pressure and volume to operate injector.
18. Injector	Mixes or injects chlorine gas into water supply. Creates sufficient vacuum to operate chlorinator and to pull metered amount of chlorine gas.
19. Solution Discharge	Discharges solution mixture of chlorine and water.

---

[22] *Pascal. The pressure or stress of one newton per square meter.*

1 psi = 6895 Pa = 6.895 kN/sq m = 0.0703 kg/sq cm

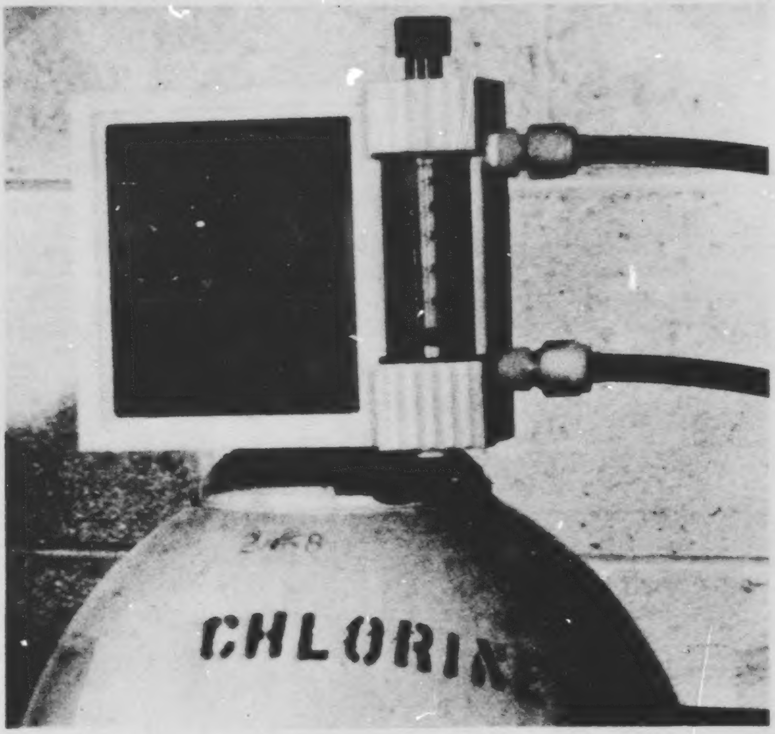
[23] *Reliquefaction (re-LICK-we-FACK-shun). The return of a gas to a liquid. For example, a condensation of chlorine gas returning to a liquid.*


SLEEVE OR OPENING NEAR CEILING
INSECT SCREEN
VENT LINE TO OUTSIDE
GAS DISPENSER
HEATER CORD (SEE NOTE 3)
HEADER (SEE NOTE 1)
ISOLATING VALVE
FLEXIBLE CONNECTOR
EJECTOR WATER SUPPLY VALVE
RELIEF VALVE
SOLUTION LINE (SEE NOTE 2)
CYLINDER VALVE
EXHAUST FAN SWITCH
UNION
WEIGHING SCALE
NEEDLE VALVE
GAS CYLINDER (SEE NOTE 4)
Y-STRAINER
WATER SUPPLY
EXHAUST FAN
BOOSTER PUMP (IF REQUIRED)

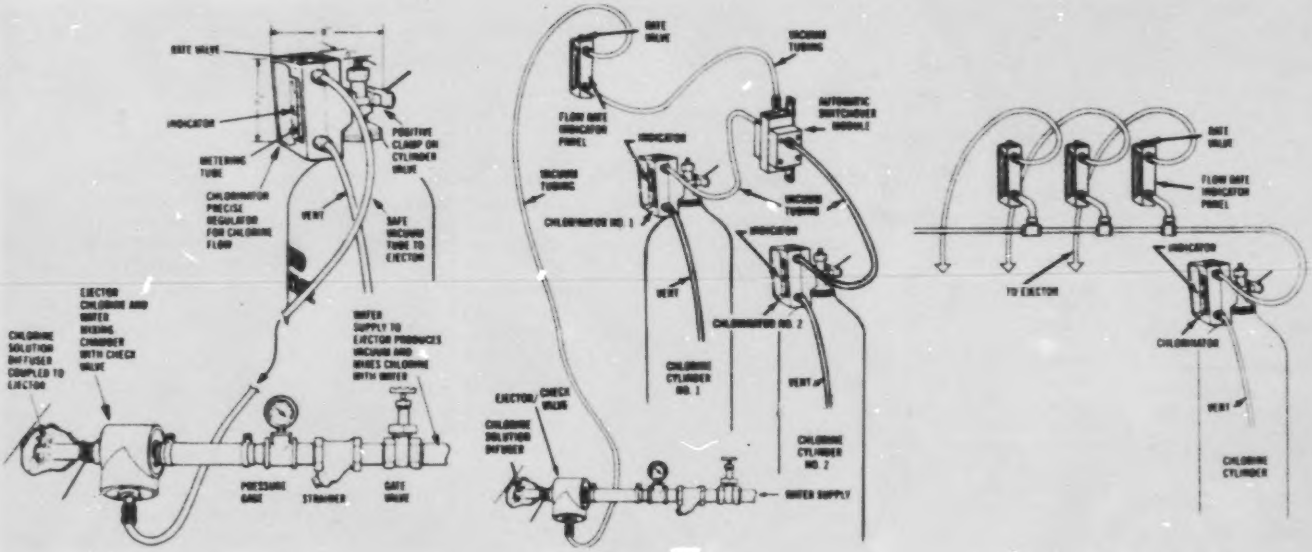
NOTES

1. USE 3/4" SCHEDULE 80 SEAMLESS CARBON STEEL PIPE FOR HEADER WITH 2000 # CWP FORGED CARBON STEEL FITTINGS.
2. SOLUTION LINE SIZE NORMALLY DEPENDS ON MAXIMUM GAS FEED RATE AND EJECTOR WATER AND BACK-PRESSURE CONDITIONS.
3. 117 V, 1Ø, 60 Hz POWER SUPPLY REQUIRED FOR HEATER.
4. NUMBER OF GAS CYLINDERS USED DEPENDS ON THE GAS WITHDRAWAL RATE OF DISPENSER.

Fig. 7.9 Typical gas dispenser installation



(Permission of Hydro Instruments, Inc.)


GATE VALVE
INDICATOR
METERING TUBE
CHLORINATOR PRECISE REGULATOR FOR CHLORINE FLOW
POSITIVE CLAMP ON CYLINDER VALVE
VENT
SAFE VACUUM TUBE TO EJECTOR
EJECTOR CHLORINE AND WATER MIXING CHAMBER WITH CHECK VALVE
CHLORINE SOLUTION DIFFUSER COUPLED TO EJECTOR
WATER SUPPLY TO EJECTOR PRODUCES VACUUM AND MIXES CHLORINE WITH WATER
PRESSURE GAGE
STRAINER
GATE VALVE
GATE VALVE
VACUUM TUBING
AUTOMATIC SWITCHOVER MODULE
FLOW RATE INDICATOR PANEL
INDICATOR
VACUUM TUBING
CHLORINATOR NO. 1
VACUUM TUBING
INDICATOR
VENT
CHLORINATOR NO. 2
CHLORINE CYLINDER NO. 1
VENT
EJECTOR/CHECK VALVE
CHLORINE SOLUTION DIFFUSER
CHLORINE CYLINDER NO. 2
WATER SUPPLY
GATE VALVE
FLOW RATE INDICATOR PANEL
INDICATOR
TO EJECTOR
CHLORINATOR
VENT
CHLORINE CYLINDER

TYPICAL
INSTALLATION
BASIC SYSTEM

TYPICAL INSTALLATION
AUTOMATIC
SWITCHOVER SYSTEM

TYPICAL INSTALLATION
REMOTE AND
MULTI-POINT SYSTEMS

(Permission of Chlorinators Incorporated)

Fig. 7.10 Cylinder-mounted gas chlorinators

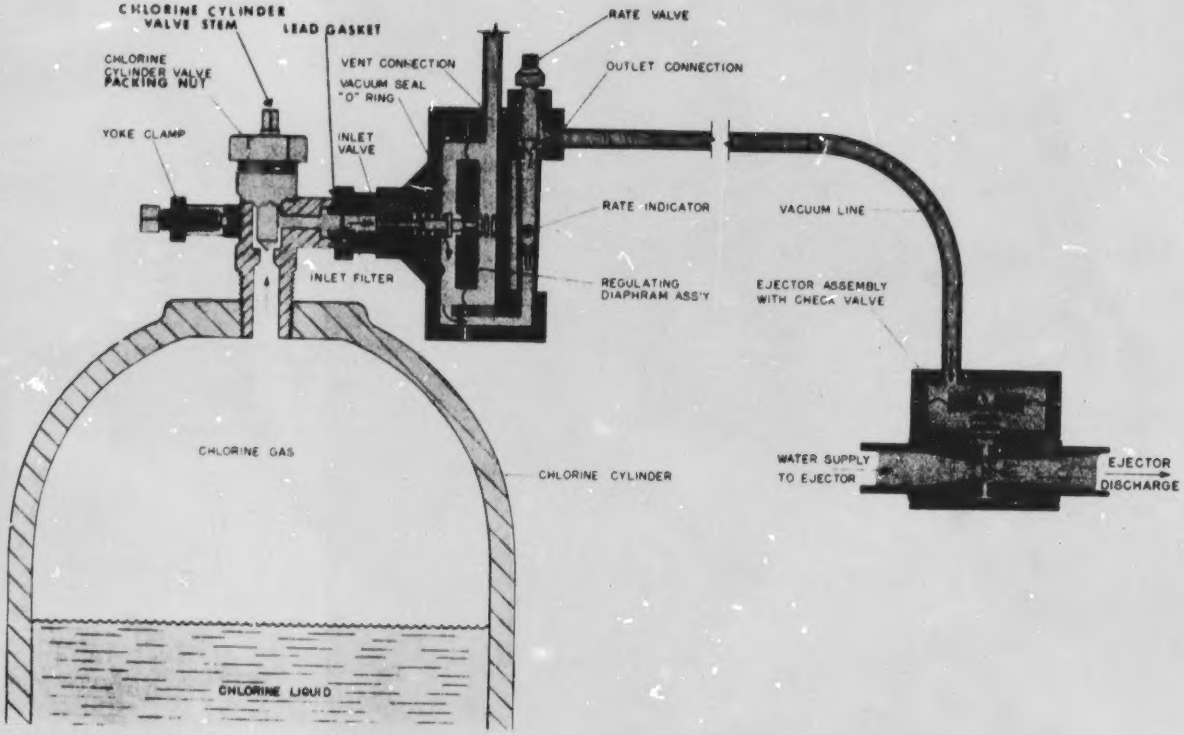

CHLORINE CYLINDER VALVE STEM
LEAD GASKET
CHLORINE CYLINDER VALVE PACKING NUT
YOKE CLAMP
VENT CONNECTION
VACUUM SEAL "O" RING
INLET VALVE
RATE VALVE
OUTLET CONNECTION
RATE INDICATOR
VACUUM LINE
INLET FILTER
REGULATING DIAPHRAM ASS'Y
EJECTOR ASSEMBLY WITH CHECK VALVE
CHLORINE GAS
CHLORINE CYLINDER
WATER SUPPLY TO EJECTOR
EJECTOR DISCHARGE
CHLORINE LIQUID

Fig. 7.11 Direct cylinder mounted connection from chlorine gas supply to chlorinator

(Permission of Capital Controls Company, Colmar, Pa.)

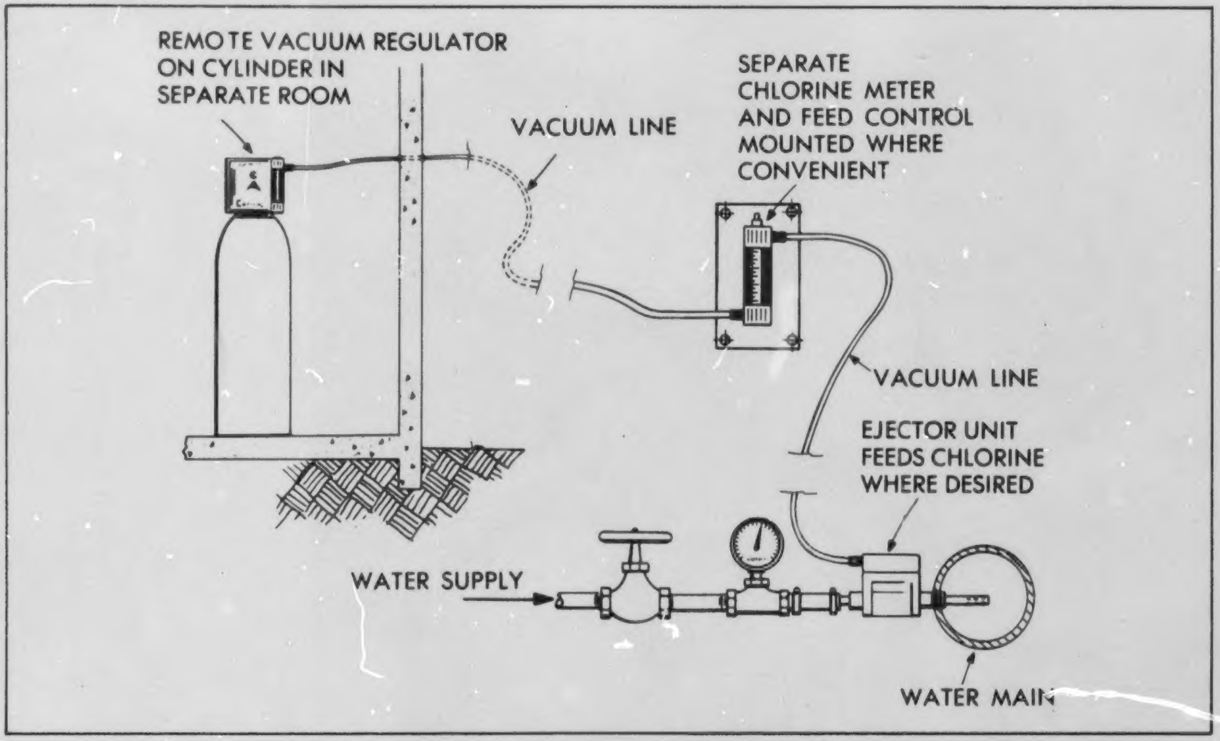

REMOTE VACUUM REGULATOR
ON CYLINDER IN
SEPARATE ROOM
VACUUM LINE
SEPARATE
CHLORINE METER
AND FEED CONTROL
MOUNTED WHERE
CONVENIENT
VACUUM LINE
EJECTOR UNIT
FEEDS CHLORINE
WHERE DESIRED
WATER SUPPLY
WATER MAIN

Fig. 7.12 Remote chlorinator with single meter and pipe installed ejector

(Permission of Capital Controls Company, Colmar, Pa.)

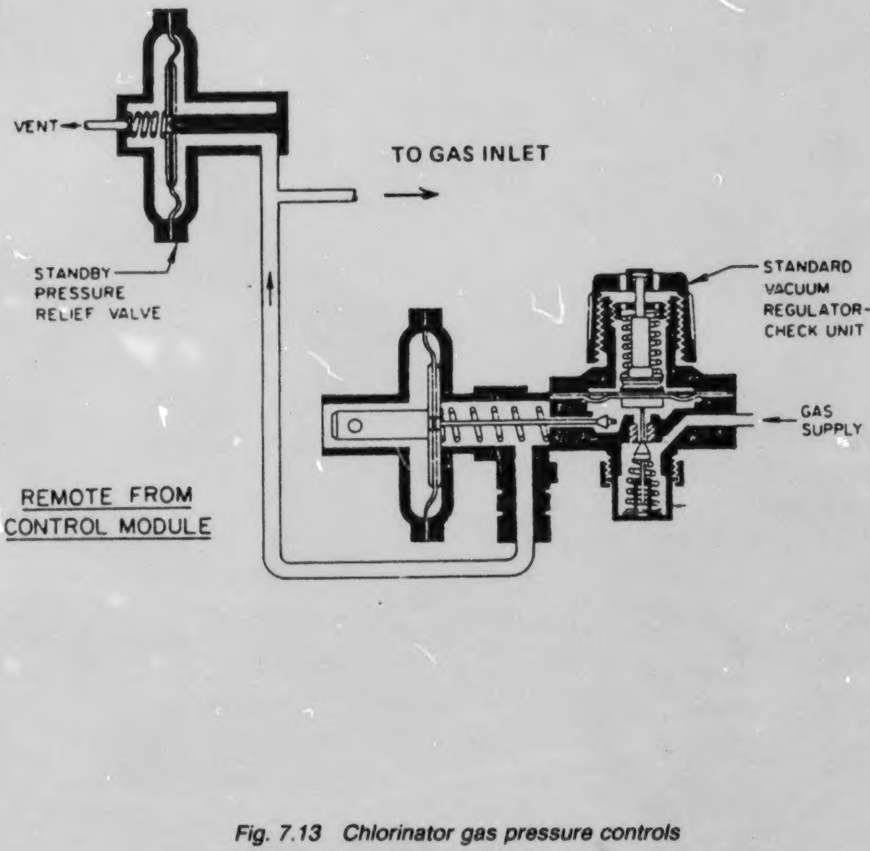

VENT
TO GAS INLET
STANDBY PRESSURE RELIEF VALVE
STANDARD VACUUM REGULATOR-CHECK UNIT
GAS SUPPLY
REMOTE FROM CONTROL MODULE

Fig. 7.13 Chlorinator gas pressure controls

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

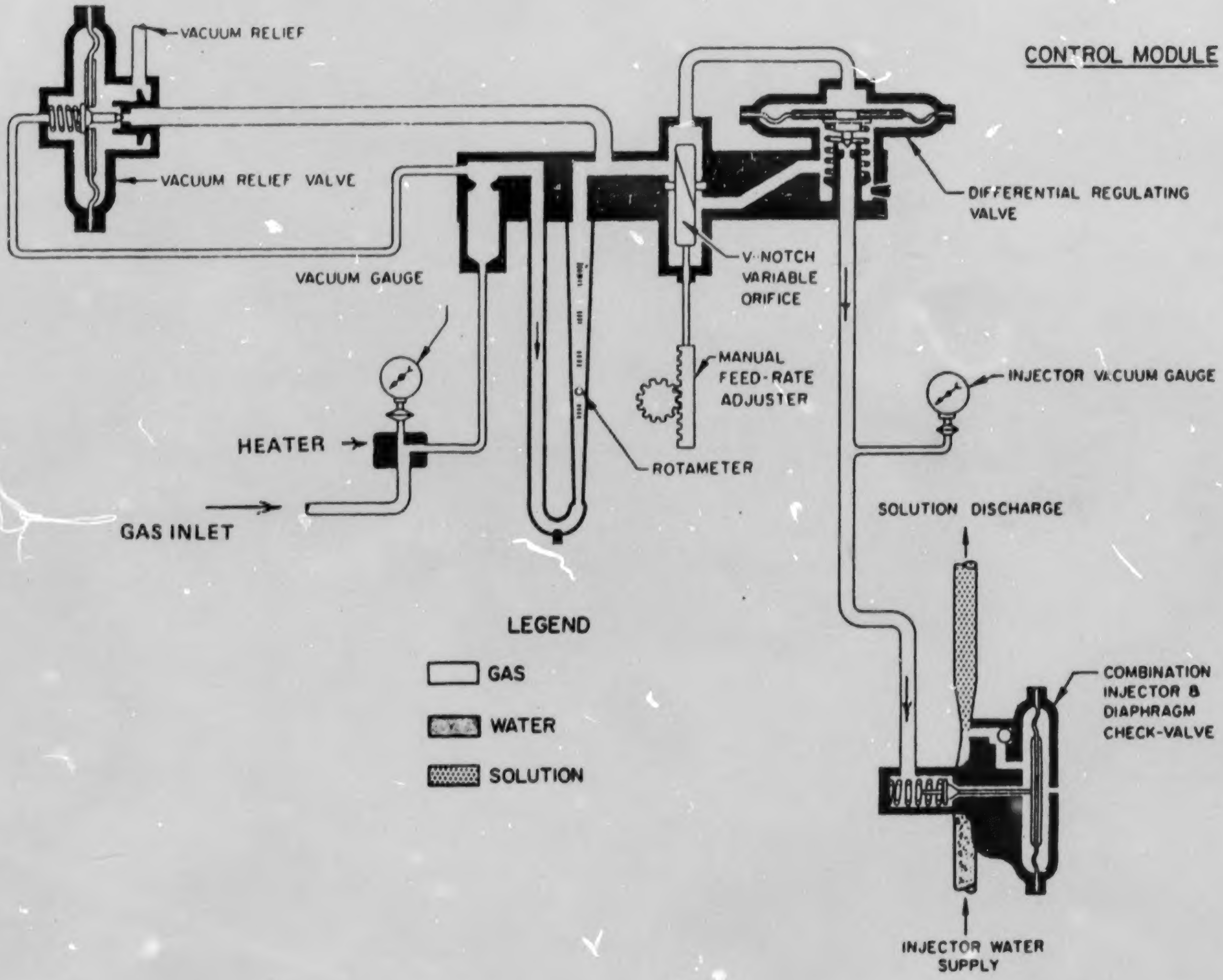
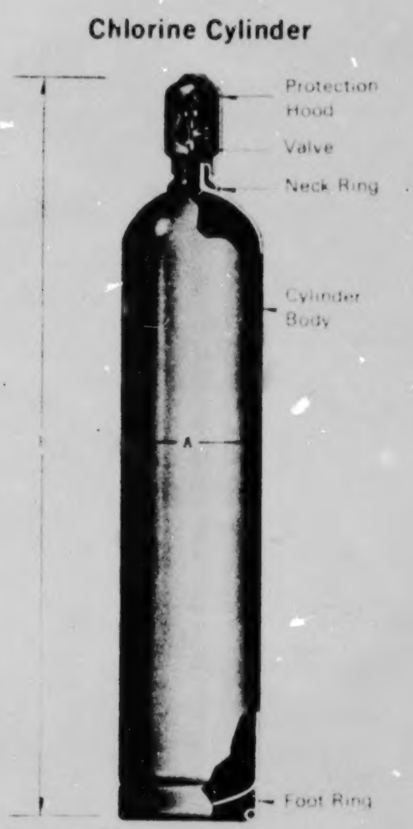

CONTROL MODULE
VACUUM RELIEF
VACUUM RELIEF VALVE
DIFFERENTIAL REGULATING VALVE
V-NOTCH VARIABLE ORIFICE
VACUUM GAUGE
MANUAL FEED-RATE ADJUSTER
INJECTOR VACUUM GAUGE
HEATER
ROTAMETER
GAS INLET
SOLUTION DISCHARGE
LEGEND
GAS
WATER
SOLUTION
COMBINATION INJECTOR & DIAPHRAGM CHECK-VALVE
INJECTOR WATER SUPPLY

Fig. 7.14 Vacuum solution-feed chlorinator

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

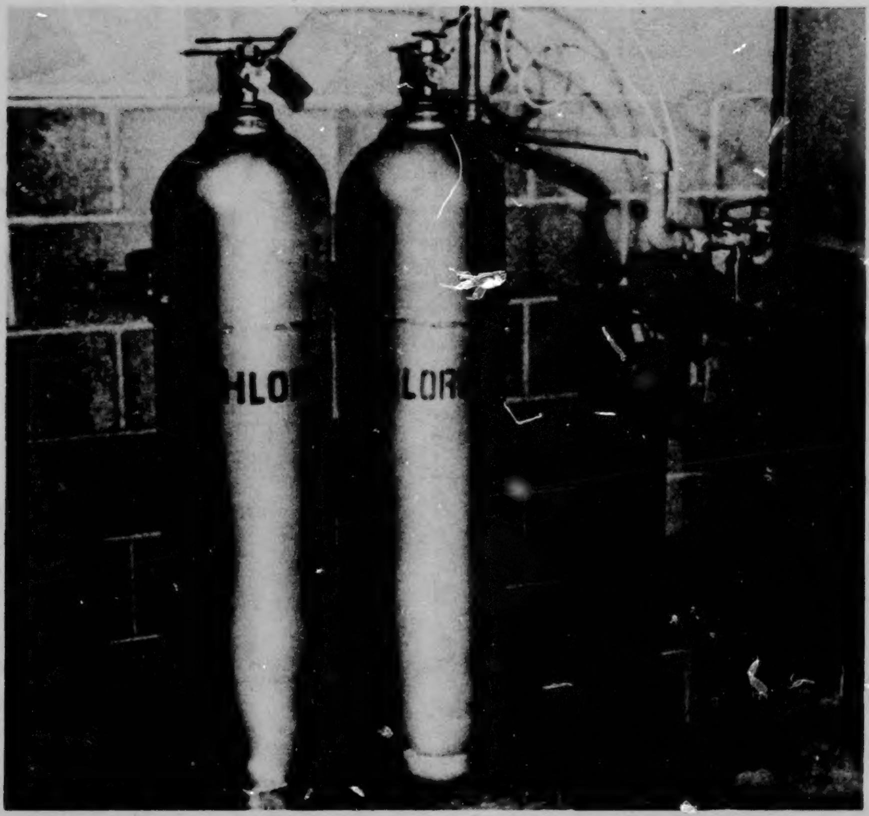

Chlorine Cylinder
Protection Hood
Valve
Neck Ring
Cylinder Body
A
Foot Ring

Net Cylinder Contents	Approx. Tare, Lbs.*	Dimensions, Inches	
		A	B
100 Lbs.	73	8¼	54½
150 Lbs.	92	10¼	54½

*Stamped tare weight on cylinder shoulder does not include valve protection hood.

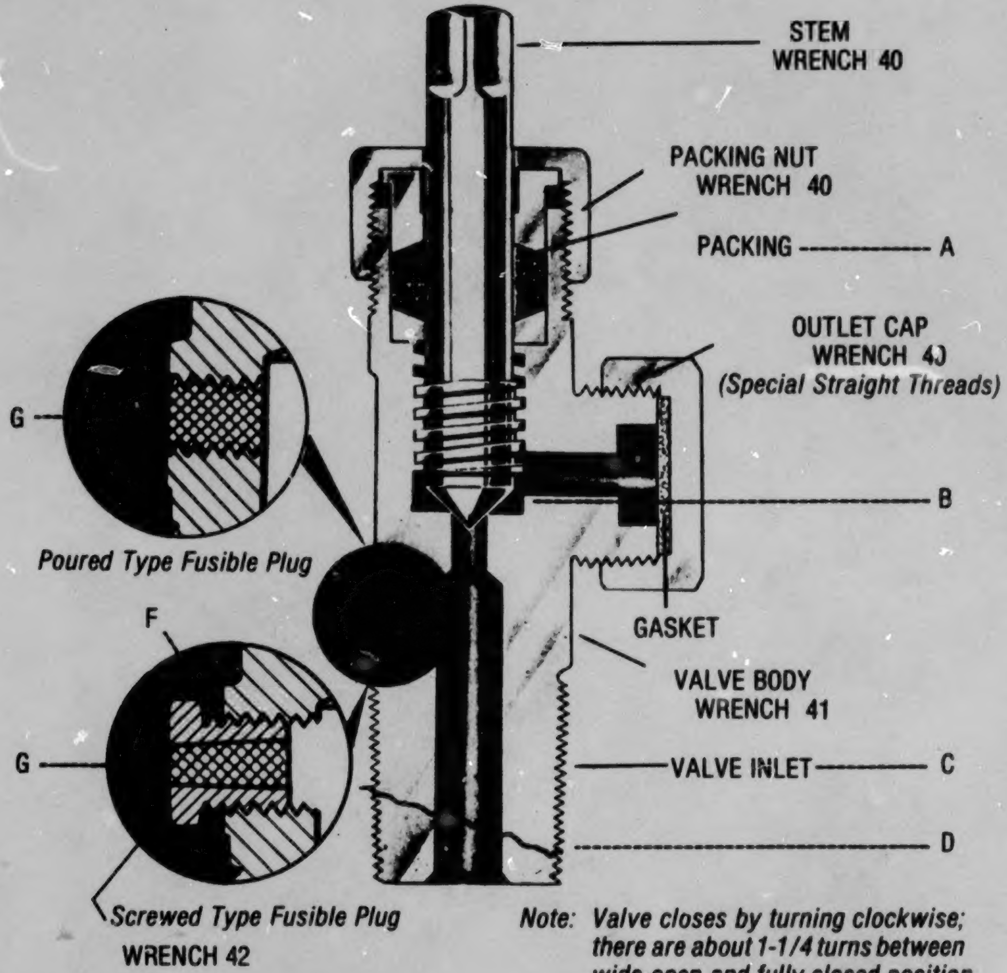
Fig. 7.15 Chlorine cylinder

(Courtesy of PPG Industries)



NOTES:
1. Scale for weighing chlorine cylinders and chlorine.
2. Flexible tubing (pig tail).
3. Cylinders chained to wall.

Fig. 7.16 Typical chlorine cylinder station for water treatment
(Courtesy of PPG Industries)


STEM
WRENCH 40
PACKING NUT
WRENCH 40
PACKING ------------ A
OUTLET CAP
WRENCH 40
(Special Straight Threads)
G
Poured Type Fusible Plug
B
GASKET
F
VALVE BODY
WRENCH 41
G
VALVE INLET ---------- C
D
Screwed Type Fusible Plug
WRENCH 42

Note: Valve closes by turning clockwise; there are about 1-1/4 turns between wide-open and fully closed position. All threads are right-hand threads.

TYPICAL VALVE LEAKS OCCUR THROUGH . . .

- A - VALVE PACKING GLAND
- B - VALVE SEAT
- C - VALVE INLET THREADS
- D - BROKEN OFF VALVE
- E - VALVE BLOWN OUT
- F - FUSIBLE PLUG THREADS
- G - FUSIBLE METAL OF PLUG
- H - VALVE STEM BLOWN OUT

Fig. 7.17 Standard chlorine cylinder valve

(Permission of Chlorine Specialties, Inc.)

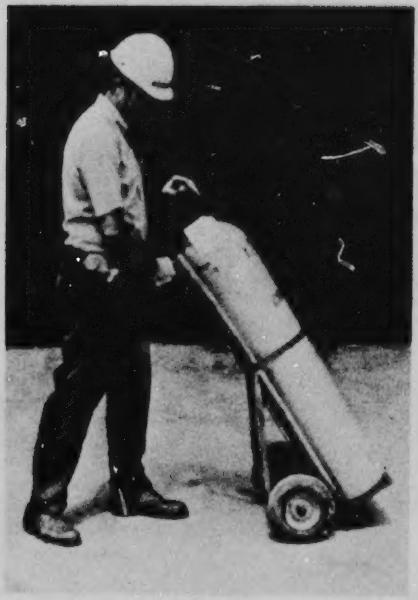


Fig. 7.18 Hand truck for chlorine cylinder
(Courtesy of PPG Industries)

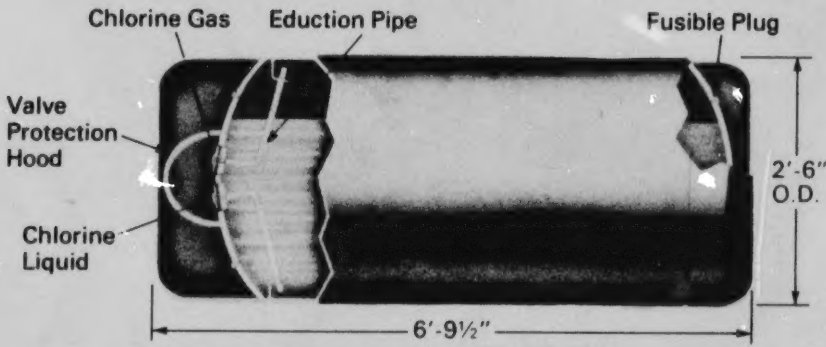

Chlorine Gas
Eduction Pipe
Fusible Plug
Valve Protection Hood
Chlorine Liquid
2′-6″ O.D.
6′-9½″

Fig. 7.19 Chlorine ton container
(Courtesy of PPG Industries)

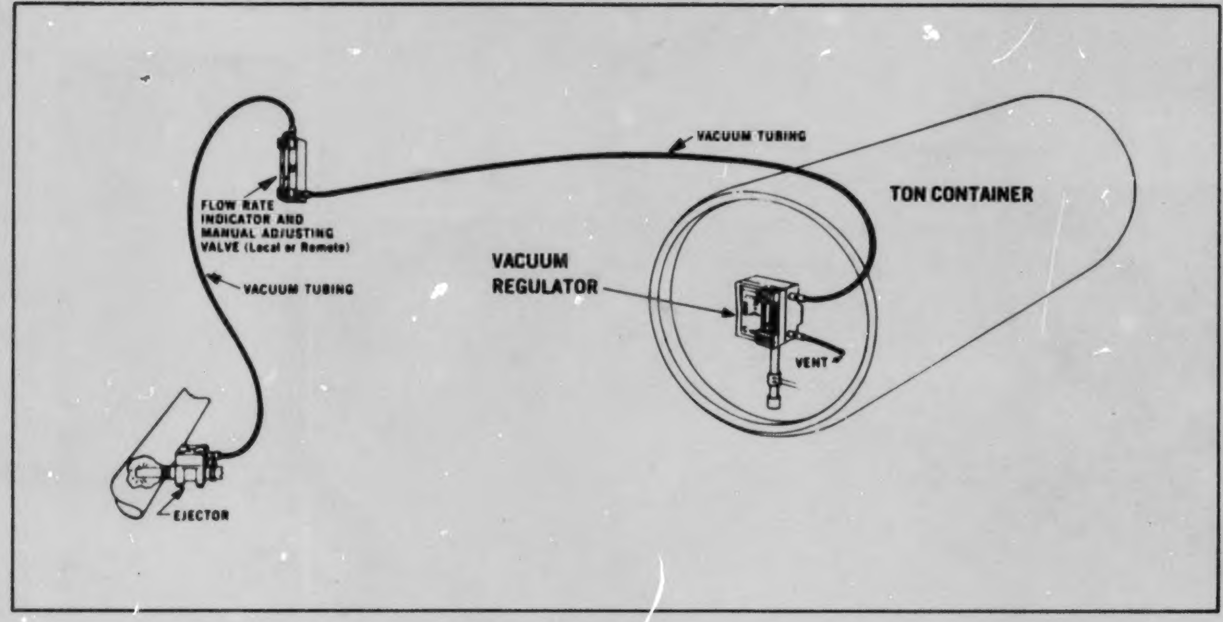
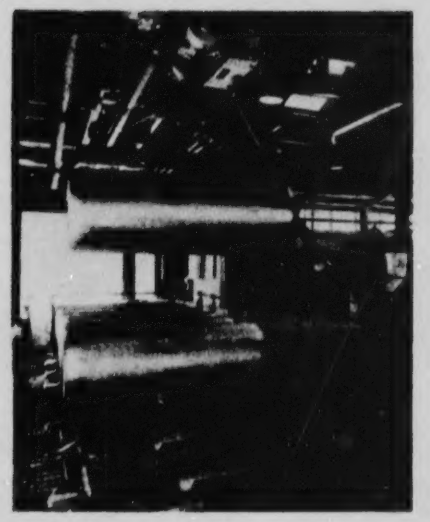

VACUUM TUBING
TON CONTAINER
FLOW RATE INDICATOR AND MANUAL ADJUSTING VALVE (Local or Remote)
VACUUM REGULATOR
VACUUM TUBING
VENT
EJECTOR

Fig. 7.20 Ton container mounted remote metering arrangement
(Permission of Capital Controls Company, Colmar, Pa.)



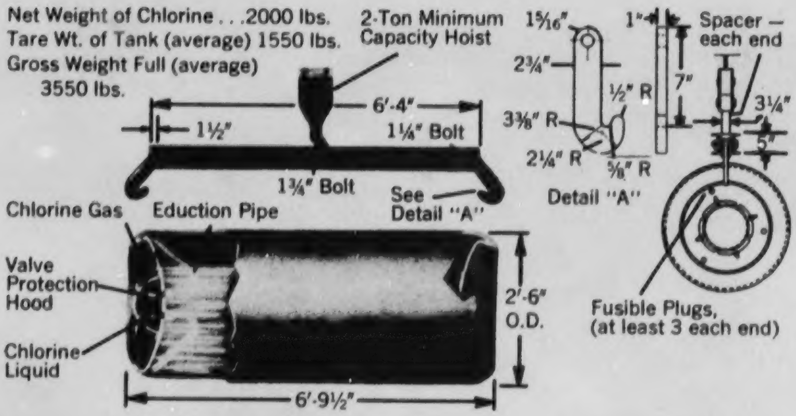

Net Weight of Chlorine . . .2000 lbs.
Tare Wt. of Tank (average) 1550 lbs.
Gross Weight Full (average)
3550 lbs.
2-Ton Minimum
Capacity Hoist
6'-4"
1½"
1¼" Bolt
1¾" Bolt
See
Detail "A"
1$\frac{5}{16}$"
1"
2¾"
½" R
7"
3⅜" R
2¼" R
⅝" R
Detail "A"
Spacer –
each end
3¼"
5"
Chlorine Gas
Eduction Pipe
Valve
Protection
Hood
Chlorine
Liquid
2'-6"
O.D.
6'-9½"
Fusible Plugs,
(at least 3 each end)

Fig. 7.21 Ton tank lifting beam

(Courtesy of PPG Industries)

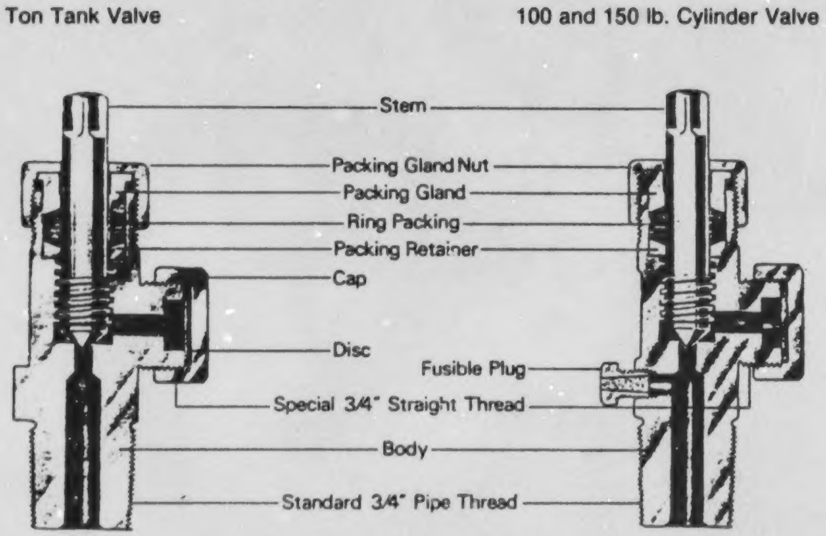

Ton Tank Valve
100 and 150 lb. Cylinder Valve
Stem
Packing Gland Nut
Packing Gland
Ring Packing
Packing Retainer
Cap
Disc
Fusible Plug
Special 3/4" Straight Thread
Body
Standard 3/4" Pipe Thread

Fig. 7.22 Comparison of ton tank valve with cylinder valve
(Courtesy of PPG Industries)

WARNING

IT IS **VERY IMPORTANT** THAT FUSIBLE PLUGS SHOULD NOT BE TAMPERED WITH **UNDER ANY CIRCUMSTANCES** AND THAT THE TANK SHOULD NOT BE HEATED. ONCE THIS PLUG OPENS, ALL OF THE CHLORINE IN THE TANK WILL BE RELEASED.

For safe handling of ton tanks, follow these procedures:

1. Ship ton tanks by rail in multi-unit cars. They also may be transported by truck or semi-trailer (Figure 7.23).
2. Handle ton tanks with a suitable lift clamp in conjunction with a hoist or crane of at least two-ton capacity (Figure 7.21).

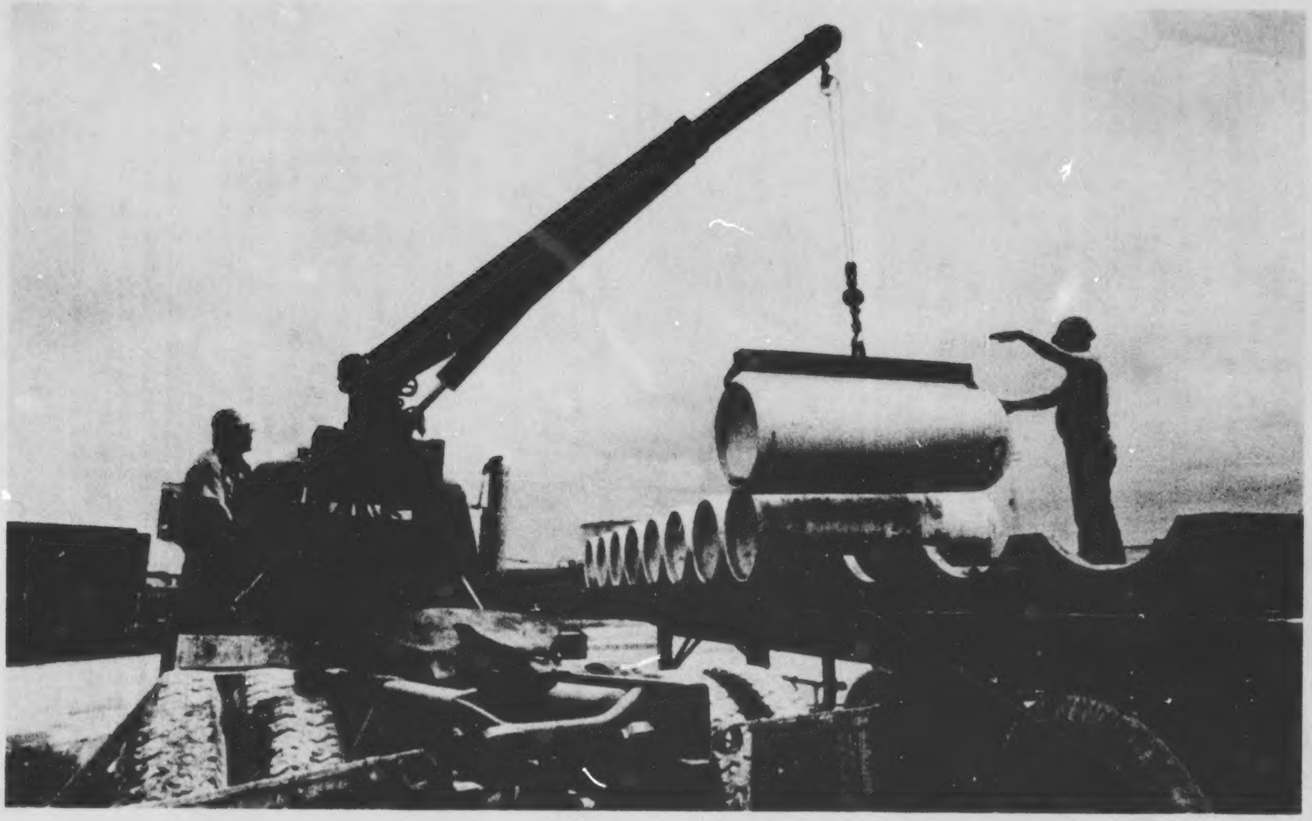


Fig. 7.23 Ton container hoist and lifting beam removing ton containers from semi-trailer

(Courtesy of PPG Industries)

313

314

3. For storage and for use, lay ton tanks on their sides, above the floor or ground, on steel or concrete supports. They should not be stacked more than one high and should be separated by 30 inches (0.75 m) for access in case of leaks.
4. Place ton tanks on trunnions (pivoting mounts) which are equipped with rollers so that the withdrawal valves may be positioned one above the other (Figure 7.24). The upper valve will discharge chlorine gas, and the lower valve will discharge liquid chlorine (see Figure 7.21).
5. Use trunnion rollers (Figure 7.24) that do not exceed 3½ inches (9 cm) in diameter so that the containers will not rotate too easily and be turned out of position.
6. Equip roller shafts with a zerk-type lubrication fitting. Roller bearings are not advised because of the ease with which they rotate.
7. Use locking devices to prevent ton tanks from rolling while connected.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 327.

7.4E What type of containers are commonly used to store hypochlorite?

7.4F How large a supply of hypochlorite should be available?

7.4G What is removed by the upper and lower valves of ton chlorine tanks?

7.4H What is the purpose of the fusible plug?

7.43 Removing Chlorine From Containers

Whenever you do any work or maintenance involving the removal of chlorine from containers, a self-contained breathing apparatus (Figure 7.25) should be worn, or at least readily available. This is especially true when searching for chlorine leaks.

7.430 Connections

The outlet threads on container valves are specialized threads; they are not ordinary tapered pipe threads. Use only the fittings and gaskets furnished by your chlorine supplier or chlorinator equipment manufacturer when making connections to chlorine containers. Do not try to use regular pipe thread fittings. Whenever you make a new connection, always use a new gasket. The outlet threads on container valves should always be inspected before being connected to the chlorine system. Containers with outlet threads which are badly worn, cross threaded or corroded should be rejected and returned to the supplier. The connecting nut on the chlorine system should also be inspected and replaced if it develops any of these problems. Since the threads on the cylinder connection may become worn, yoke-type connectors (Figure 7.26) are recommended.

Flexible ⅜-inch 2000-pound (psi) (0.95 cm, 13,790 kPa or 140 kg/sq cm) annealed (toughened) copper tubing (pig tail, see Figure 7.16) is recommended for connections between chlorine containers and stationary piping. Care should be taken to prevent sharp bends in the tubing because this will weaken it and eventually the tubing will start leaking. Many operators recommend use of a sling to hold the tubing when disconnecting it from an empty cylinder to prevent the tubing from flopping around and getting kinked or getting dirt inside it.

To simplify changing containers, you will also need a shutoff valve located just beyond the container valve or at the beginning of the stationary piping.

7.431 Valves

Do not use wrenches longer than six inches (15 cm), pipe wrenches, or wrenches with an extension on container valves. If you do, you could exert too much force and break the valve. Use only a 31-inch square end-open or box wrench (see Figure 7.26) (this wrench can be obtained from your chlorine supplier). To unseat the valve, strike the end of the wrench with the heel of your hand to rotate the valve stem in a counter-clockwise direction. Then open slowly. One complete turn permits maximum discharge. Do not force the valve beyond this point. If the valve is too tight to open in this manner, loosen the packing gland nut (Figure 7.22) slightly to free the stem. If you are uncertain how to loosen the nut, you should return the container to the supplier.

7.432 Ton Tanks

One-ton tanks (Figure. 7.21) must be PLACED ON THEIR SIDES WITH THE VALVES IN A VERTICAL POSITION so either chlorine gas or liquid chlorine may be removed. Connect the flexible tubing to the TOP VALVE to remove chlorine gas from a tank (Figure 7.27). The BOTTOM VALVE is used to remove liquid chlorine and is used only with a chlorine evaporator. The valves are similar to those on the smaller chlorine cylinders (fusible plugs are not located at valves on ton containers) and must be handled with the same care.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.4I How can copper tubing be prevented from getting kinks or dirt inside the tubing?

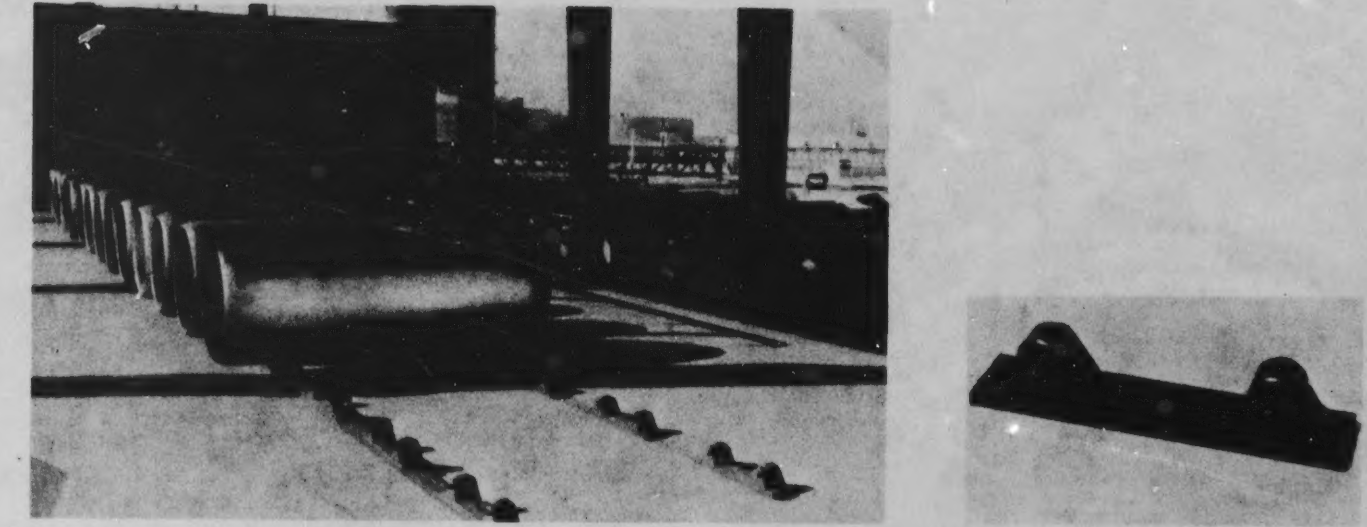
7.4J Why are one-ton tanks placed on their sides with the valves in a vertical position?

7.44 Performance of Chlorine Units

Before attempting to start or stop any chlorination system, read the manufacturer's literature and your plant's operation and maintenance instructions to become familiar with the equipment. Review the plans and drawings of the facility. Determine what equipment, pipelines, pumps, tanks and valves are to be placed into service or are in service. The current status of the entire system must be known before starting or stopping any portion of the system. This section provides the procedures for a typical system and will give you ideas for your system.

7.440 Hypochlorinators

1. *STARTUP OF HYPOCHLORINATORS*
   a. Prepare the chemical solution. Most agencies buy commercial or industrial hypochlorite at a strength of 12 to 14 percent chlorine. This solution is usually diluted down to a two percent solution. If using commercially prepared solutions, you will need to calculate feed rates.



Trunnions for rotating ton containers

Close-up of trunnions in photo at left

Fig. 7.24 Storage of ton containers

(Courtesy of PPG Industries)

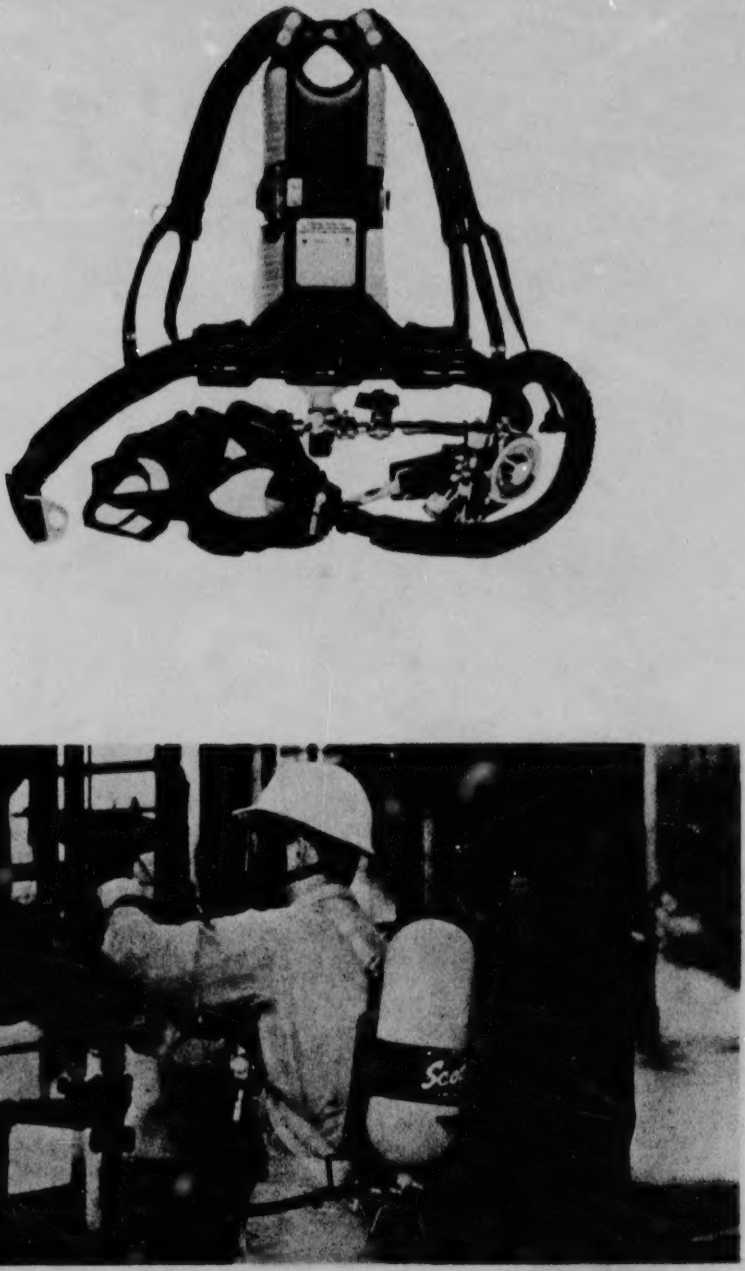


Fig. 7.25 Self-contained breathing apparatus
(Courtesy of PPG Industries)

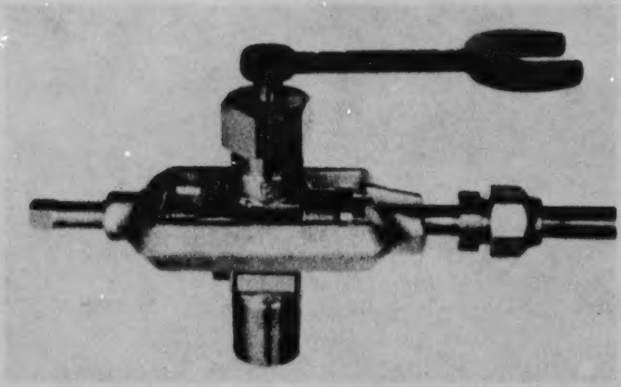


Fig. 7.26 Yoke and adapter-type connection

(Permission of The Chlorine Institute, Inc.)

b. Lock out the electrical circuit and then inspect it. Normally no adjustments are needed. Look for frayed wires. Turn power back on. Leave solution switch off.

c. Turn on the chemical pump. Make adjustments while the pump is running. Never adjust while pump is off because damage to pump will occur.

d. Calibrate pump to insure accurate delivery of chlorine solution. See Chapter 4, "Coagulation and Flocculation," Appendix B, "Adjustment and Calibration of Chemical Feeders."

e. Make sure solution is being fed into system. Measure chlorine residual just downstream from where solution is being fed into system. You may have a target residual you wish to maintain at the beginning of the system such as 2.0 mg/*L*.

f. Check chlorine residual in system. Residual should be measured at the most remote test location within the distribution system and should be at least 0.2 mg/*L* free residual chlorine. This chlorine residual is necessary to protect the treated water from any recontamination. Adjust chemical feed as needed.

2. *SHUTDOWN OF HYPOCHLORINATORS*

a. Short Duration

(1) Turn water supply pump off. You do not want to pump any unchlorinated water and possibly contaminate the rest of the system. *NEVER PUMP ANY UNCHLORINATED WATER INTO YOUR DISTRIBUTION SYSTEM.*

(2) Turn hypochlorinator off.

(3) When making repairs, lock out circuit or pull plug from electric socket.

b. Long Duration

(1) Obtain and/or place another hypochlorinator in service.

3. *NORMAL OPERATION OF HYPOCHLORINATORS*

Normal operation of a hypochlorinator requires routine observation and preventive maintenance.

DAILY

a. Inspect building to make sure only authorized personnel have been there.

b. Read and record level of solution tank at the same time every day.

c. Read meters and record the amount of water pumped.

d. Check chlorine residual (at least 0.2 mg/*L*) in system and adjust chlorine feed rate as necessary.

e. Check chemical feed pump operation. Most hypochlorinators have a dial with a range from 0 to 10 which adjusts the chlorine feed rate. Start with a setting around 7 or 8 on the dial and a two-percent hypochlorite solution. The pump should operate in the upper ranges of the dial so that the strokes or pulses from the pump will be close together. In this way, the chlorine will be fed continuously to the water being treated.

WEEKLY

a. Check chemical dose. Note the solution level in the hypochlorinator and read the water meter or note how many hours the water pump was in operation. With these figures, calculate the actual chemical dose. See EXAMPLE 3.

b. Make sure every piece of equipment is operating normally.

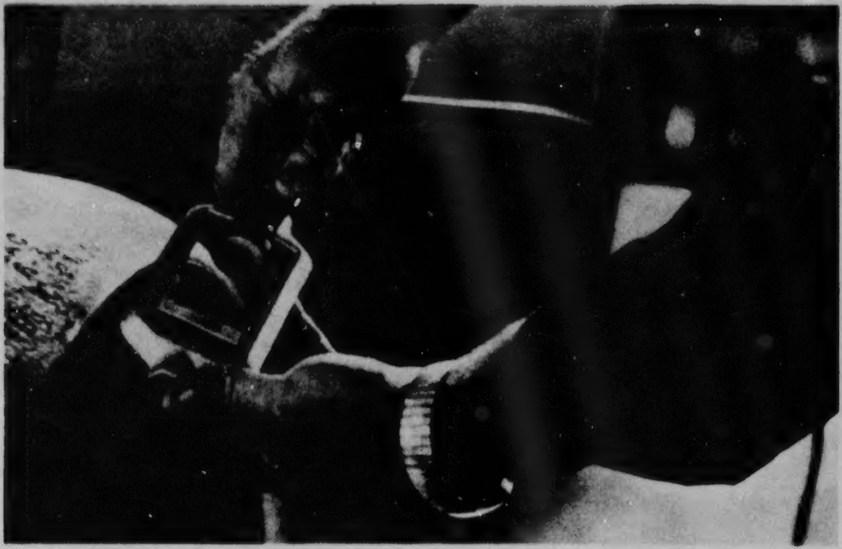
c. Inspect lubrication.

d. Check building for problems.

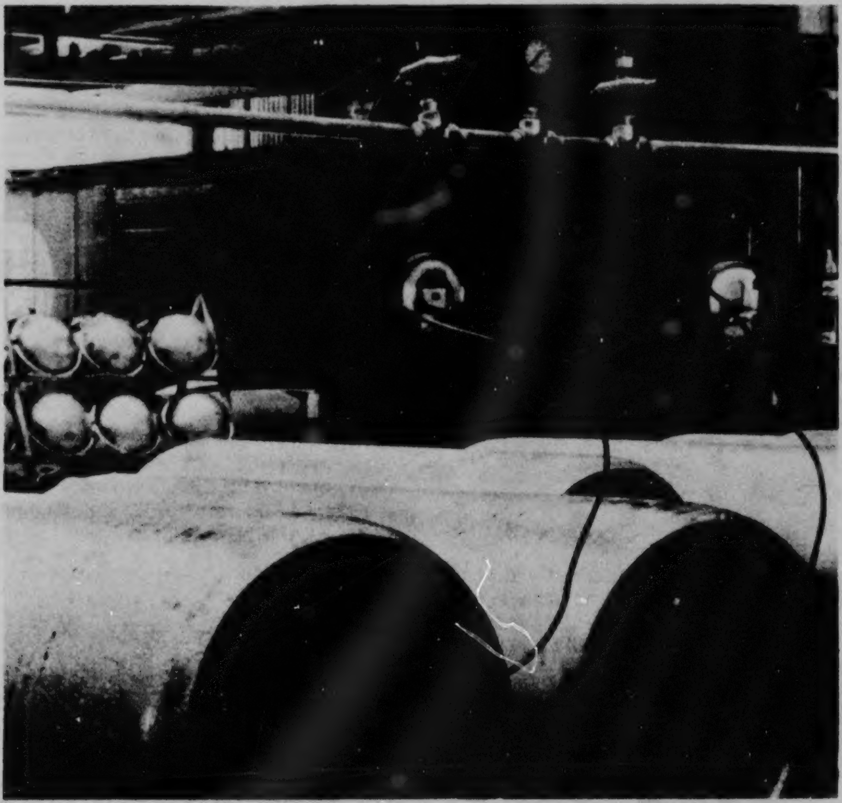
e. Clean area.

FORMULAS

When operating a hypochlorinator you should compare the actual chlorine dose applied to the water being treated with the desired chlorine dose in milligrams per liter. The actual dose is calculated by determining the amount of chlorine actually used and the amount of water treated. The amount of chlorine used is found by measuring the amount of hypochlorite solution used and knowing the strength of the hypochlorite solution. The amount of water used is determined from a flow meter.



Yoke and adaptor for ton container valve connection



Manifolded gas valves of ton containers

Fig. 7.27 Withdrawing chlorine from ton containers
(Courtesy of PPG Industries)

To calculate the amount of water treated, determine the amount in gallons from a flow meter and convert this amount from gallons to pounds.

$$\text{Water, lbs} = (\text{Water Treated, gal})(8.34\ \text{lbs/gal})$$

To calculate the amount of hypochlorite used in gallons, determine the volume of hypochlorite used in gallons.

$$\text{Hypochlorite, gallons} = (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})$$

To determine the pounds of chlorine used to disinfect the water being treated, we have to convert the hypochlorite used from gallons to pounds of chlorine by considering the strength of the hypochlorite solution.

$$\text{Chlorine, lbs} = \frac{(\text{Hypochlorite, gal})(8.34\ \text{lbs/gal})(\text{Hypochlorite, \%})}{100\%}$$

Finally, to estimate the actual chlorine dose in milligrams of chlorine per liter of water treated, we divide the pounds of chlorine used by the millions of pounds of water treated (ppm = mg/*L*).

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}$$

EXAMPLE 3

Water pumped from a well is disinfected by a hypochlorinator. A chlorine dose of 1.2 mg/*L* is necessary to maintain an adequate chlorine residual throughout the system. During a one-week time period, the water meter indicated that 2,289,000 gallons of water were pumped. A two-percent sodium hypochlorite solution is stored in a three-foot diameter plastic tank. During this one week period, the level of hypochlorite in the tank dropped 2 feet, 8 inches (2.67 feet). Does the chlorine feed rate appear to be too high, too low or about OK?

Known		Unknown
Desired Chlorine Dose, mg/*L*	= 1.2 mg/*L*	1. Actual Chlorine Dose, mg/*L*
Water Pumped, gal	= 2,289,000 gal	2. Is Actual Dose OK?
Hypochlorite, %	= 2%	
Chemical Tank Diameter, ft	= 3 ft	
Chemical Drop in Tank, ft	= 2.67 ft	

1. Calculate the pounds of water disinfected.

$$\begin{aligned}\text{Water, lbs} &= (\text{Water Pumped, gallons})(8.34\ \text{lbs/gal})\\ &= (2{,}289{,}000\ \text{gal})(8.34\ \text{lbs/gal})\\ &= 19{,}090{,}000\ \text{lbs}\\ &= 19.09\ \text{Million lbs}\end{aligned}$$

2. Calculate the volume of two-percent sodium hypochlorite used in gallons.

$$\begin{aligned}\text{Hypochlorite, gallons} &= (0.785)(\text{Diameter, ft})^2(\text{Depth, ft})(7.48\ \text{gal/cu ft})\\ &= (0.785)(3\ \text{ft})^2(2.67\ \text{ft})(7.48\ \text{gal/cu ft})\\ &= 141.1\ \text{gallons}\end{aligned}$$

3. Determine the pounds of chlorine used to disinfect the water.

$$\begin{aligned}\text{Chlorine, lbs} &= (\text{Hypochlorite, gal})(8.34\ \text{lbs/gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)\\ &= (141.1\ \text{gal})(8.34\ \text{lbs/gal})\left(\frac{2\%}{100\%}\right)\\ &= 23.5\ \text{lbs chlorine}\end{aligned}$$

4. Estimate the chlorine dose in mg/*L*.

$$\begin{aligned}\text{Chlorine Dose, mg}/L &= \frac{\text{Chlorine, lbs}}{\text{Water, Million lbs}}\\ &= \frac{23.5\ \text{lbs chlorine}}{19.09\ \text{Million lbs water}}\\ &= 1.2\ \text{mg}/L\end{aligned}$$

Since actual estimated chlorine dose (1.2 mg/*L*) was similar to the desired dose of 1.2 mg/*L*, the chlorine feed rate appears OK.

4. *ABNORMAL OPERATION OF HYPOCHLORINATORS*

a. Inform Supervisor.

b. If hypochlorinator malfunctions, repair or replace immediately. See shut down operation.

c. Solution tank level.

(1) Too Low — Check adjustment of pump.
Check hour meter of water pump.

(2) Too High — Check chemical pump.
Check hour meter of water pump.

d. Chemical pump not operating.

TROUBLESHOOTING GUIDELINES

(1) Check electrical connection.

(2) Check circuit breaker.

(3) Check for stoppages.

CORRECTIVE MEASURES

(1) Shut off water pump so that no unchlorinated water is pumped into system.

(2) Check for blockage in solution tank.

(3) Check operation of check valve.

(4) Check electrical circuits.

(5) Replace chemical feed pump with another while repairing.

e. Solution not pumping.

TROUBLESHOOTING

(1) Check solution level.

(2) Check for blockages.

5. *MAINTENANCE OF HYPOCHLORINATORS*

Hypochlorinators on small systems may be sealed systems and cannot be repaired so replacement is the only solution. Some units are repairable and can be served by following manufacturer's instructions. Maintenance requirements are normally minor such as oil changes and lubrication. Review the manufacturer's specifications and instructions for requirements.

Commercial sodium hypochlorite solutions (such as chlorox) contain an excess of caustic (sodium hydroxide or NaOH). When this solution is diluted with water containing calcium and also carbonate alkalinity, the resulting solution becomes supersaturated with calcium carbonate. This calcium carbonate tends to form a coating on the poppet valves in the solution feeder. The coated valves will not seal properly and the feeder will fail to feed properly.

Use the following procedure to remove the carbonate scale:

1. Place one fluid ounce (20 mL) of 30 to 37 percent hydrochloric acid (swimming pool acid) in a one quart (one liter) Mason jar.
2. Fill the jar with tap water.
3. Place the suction hose of the hypochlorinator in the jar and pump the entire contents of the jar through the system.
4. Return the suction hose to the hypochlorite solution tank and resume normal operation.

You can prevent the formation of the calcium carbonate coatings by obtaining the dilution water from an ordinary home water softener.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.4K What should be the chlorine residual in the most remote part of the distribution system?

7.4L Why should a hypochlorite feed pump be operated in the upper end of its range (at 7 or 8 in a range of 0 to 10)?

7.441 Chlorinators

1. *STARTUP OF CHLORINATORS*

Procedures for startup, operation, shutdown and troubleshooting are outlined in this section and are intended to be typical procedures for all types of chlorinators. For specific directions, see manufacturer's literature and operation and maintenance instructions for your plant. During emergencies you must act quickly and may not have time to check out each of the steps outlined below, but you still must follow established procedures.

A. Gas Chlorinators

Startup procedures for chlorinators using chlorine gas from containers are outlined in this section.

1. Be sure chlorine gas valve at the chlorinator is closed. This valve should already be closed since the chlorinator is out of service.
2. All chlorine valves on the supply line should have been closed during shutdown. Be sure they are still closed. If any valves are required to be open for any reason, this exception should be indicated by a tag on the valve.
3. Inspect all tubing, manifold and valve connections for potential leaks and be sure all joints are properly gasketed.
4. Check chlorine-solution distribution lines to be sure that system is properly valved to deliver chlorine solution to desired point of application.
5. Open the chlorine metering orifice slightly by adjusting chlorine feed-rate control.
6. Start the injector water supply system. This is usually a potable water supply protected by an *AIR GAP*[24] or air-break system. Injector water is pumped at an appropriate flow rate and the flow through the injector creates sufficient vacuum in the injector to draw chlorine. Chlorine is absorbed and mixed in the water at the injector. This chlorine solution is conveyed to the point of application.
7. Examine injector water supply system.
   - a. Note reading of injector-supply pressure gage. If reading is abnormal (different from usual reading), try to identify cause and correct.
   - b. Note reading of injector vacuum gage. If system does not have a vacuum gage, have one installed. If the vacuum reading is less than normal, the machine may function at a lower feed rate, but will be unable to deliver at rated capacity.
8. Inspect chlorinator vacuum lines for leaks.
9. Crack open the chlorine container valve and allow gas to enter the line. Inspect all joints for leaks by placing an ammonia-soaked rag[25] near each joint. The formation of a white cloud or vapor will indicate a chlorine leak. Start with the valve at the chlorine container, move down the line and check all joints between this valve and the next one downstream. *NEVER* apply ammonia solutions directly to any valve because an acid will form which will eat away the valve fittings. If the downstream valve passes the ammonia test, open the valve and continue to the next valve. If there are no leaks to the chlorinator, continue with the startup procedure.
10. Inspect the chlorinator.
    - a. Chlorine gas pressure at the chlorinator should be between 20 and 30 psi (137.9 kPa to 206.85 kPa or 1.4 to 2.1 kg/sq cm). However, in the summer on very hot days the pressure in a chlorine cylinder may exceed 150 psi (1035 kPa or 10.5 kg/sq cm).
    - b. Operate chlorinator at complete range of feed rates.
    - c. Check operation on manual and automatic settings.
11. Chlorinator is ready for use. Set chlorinator at desired feed rate. Log in the time the system is placed into operation and the application point.

B. Chlorinators with Evaporators[26] (Figure 7.28)

Startup procedures for chlorinators using liquid chlorine from containers are outlined in this section.

1. Inspect all joints, valves, manifolds and tubing connections in chlorination system, including application lines for proper fit and for leaks. Make sure that all joints have gaskets.
2. If chlorination system has been broken open or exposed to the atmosphere, verify that the system is dry. Usually, once a system has been dried out,

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[24] *Air Gap. An open vertical drop, or vertical empty space, between drinking (potable) water supply and the point of use in a water treatment plant or other location. This gap prevents back siphonage because there is no way raw water can reach the potable water.*

[25] *Use a concentrated ammonia solution containing 28 to 30 percent ammonia as NH_3 (this is the same as 58 percent ammonium hydroxide, NH_4OH, or commercial 26° Baume).*

[26] *Only the very largest water treatment plants require chlorinators equipped with evaporators.*

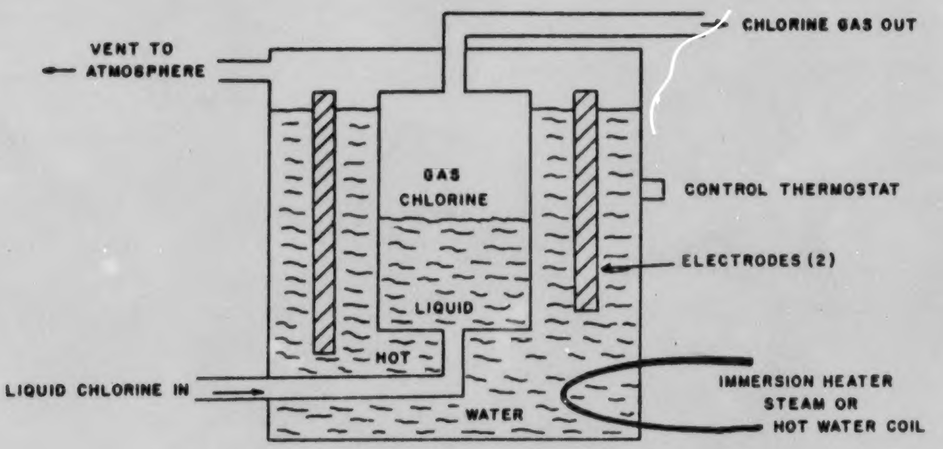

Fig. 7.28 Liquid chlorine evaporator

(Source: Basic Gas Chlorination Workshop Manual, 1972, published by Training and Licensing Section, Ministry of Environment, Ontario, Canada)

it is never opened again to the atmosphere. However, if moisture enters the system in the air or by other means, it readily mixes with chlorine and forms hydrochloric acid which will corrode the pipes, valves, joints and fittings. *CORROSION CAN CAUSE LEAKS AND REQUIRE THAT THE ENTIRE SYSTEM BE REPLACED.*

To verify that the system is dry, determine the *DEW POINT*[27] (must be lower than 40°F or 5°C). If not dry, turn the evaporator on, pass dry air through the evaporator and force this air through the system. If this step is omitted and moisture remains in the system, serious corrosion damage can result and the entire system may have to be repaired.

3. Start up the evaporators. Fill the water bath and adjust the device according to the manufacturer's directions. Water baths or evaporators should be equipped with low water alarms and automatic shutoffs in case of excessive heat. Melt down can occur with lack of water and chlorine is explosive at high temperatures.
4. Turn on the heaters on the evaporators.
5. Wait until the temperature of the evaporators reaches 180°F (82°C). This may take over an hour on large units.
6. Inspect and close all valves on the chlorine supply line.
7. Open the chlorine-metering orifice slightly. This is to prevent damage to the rotameter.
8. Start the injector water supply system.
9. Examine injector water supply system.
   a. Note reading of injector water supply pressure gage. If gage reading is abnormal (different than usual reading), try to identify the cause and correct it.
   b. Note reading of injector vacuum gage. If system does not have a vacuum gage, have one installed. If the vacuum reading is less than normal, the machine may function at a lower feed rate, but will be unable to deliver at rated capacity.
10. Inspect chlorinator vacuum lines for leaks.
11. Close all valves on the supply line.
12. Crack open the CHLORINE GAS LINE at the chlorine container. All liquid chlorine systems should be checked by using gas because of the danger of leaks (one liter of liquid will produce 450 liters of gas). Inspect the joints between this valve and the next one downstream. If this valve passes the ammonia leak test, continue to the next valve down the line. Follow this procedure until the evaporator is reached. Before allowing chlorine to enter the evaporator and the chlorinator, make sure that all valves between the evaporator and the chlorinator are open. Heat in the evaporator will expand the gas, and if the system is closed, there could be problems. Chlorine should never be trapped in a line between the evaporator and the chlorinator.
13. If no problems develop, the gas line can be put in service by opening the valve 1½ to 2 turns.
14. Check the operation of the chlorinator.
   a. Operate over complete range of chlorine feed rates.
   b. Check operation on manual and automatic settings.
15. Inspect the liquid chlorine control valve. If OK, open the liquid chlorine control valve.

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[27] *Dew Point. The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air. Dew point test equipment and procedures are available from Lectrodryer Division, Magnethermic Corporation, P.O. Box 4599, Pittsburgh, PA 15205, and Alnor Instrument Company, 420 North LaSalle Street, Chicago, IL 60610.*

16. After admitting liquid chlorine to the system, wait until the temperature of the evaporator again reaches 180°F (82°C) and full working pressure (100 psi, 690 kPa or 7 kg/sq cm). Inspect the evaporator by looking for leaks around pipe joints, unions and valves.

17. The system is ready for normal operation.

2. *SHUTDOWN OF A CHLORINATOR*

A. Short-Term Shutdown

The following is a typical procedure for shutting down a chlorinator for a time period of less than one week.

1. Close chlorine container gas outlet valve.
2. Allow chlorine gas to completely evacuate the system through the injector. Chlorine gas pressure gages will fall to zero psi on the manifold and the chlorinator.
3. Close chlorinator gas discharge valve. The chlorinator may remain in this condition indefinitely and is ready to be placed back in service by reopening the chlorinator discharge valve and the chlorine container gas outlet valve. After these valves have been reopened, inspect for chlorine leaks throughout the chlorination system.

B. Long-Term Shutdown

1. Perform steps one, two and three above for short-term shutdown.
2. Turn off chlorinator power switch, lock out and tag.
3. Secure chlorinator gas manifold and chlorinator valve in closed position.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.4M When starting a gas chlorinator, how is the system checked for chlorine gas leaks?

7.4N List the steps to follow when shutting down a chlorinator for a long time period.

7.4O What would you do before attempting to start any chlorination system?

7.45 Normal and Abnormal Operation

Normal operation of the chlorination process requires regular observation of facilities and a regular preventive maintenance program. When something abnormal is observed or discovered, corrective action must be taken. This section outlines normal operation procedures and also responses to abnormal conditions. Exact procedures will depend on the type of equipment in your plant.

7.450 Container Storage Area

DAILY

1. Inspect building or area for ease of access by authorized personnel to perform routine and emergency duties.
2. Be sure fan and ventilation equipment are operating properly.
3. Read scales, charts or meters at the same time every day to determine use of chlorine and any other chemicals. Notify plant superintendent when chlorine supply is low.
4. Look at least once per shift for chlorine and chemical leaks.
5. Try to maintain temperature of storage area below temperature of chlorinator room.
6. Determine manifold pressure before and after chlorine pressure regulating valve.
7. Be sure all chlorine containers are properly secured.

WEEKLY

1. Clean building or storage area.
2. Check operation of chlorine leak-detector alarm.

MONTHLY

1. Exercise all valves, including flex connector's auxiliary, manifold, filter bypass, and switchover valves.
2. Inspect all flex connectors and replace any that have been kinked or flattened.
3. Inspect hoisting equipment.
    a. Cables: frayed or cut.
    b. Beams and hooks: cracked or bent.
    c. Controls: operate properly; do not stick or respond sluggishly; cords not frayed; safety chains or cables in place.
4. Examine building ventilation.
    a. Ducts and louvers: clean and operate freely.
    b. Fans and blowers: operate properly; guards in place; equipment properly lubricated.
5. Perform preventive maintenance as scheduled. These duties may include:
    a. Lubricating equipment.
    b. Repacking of valves and regulators.
    c. Cleaning and replacing of valve seats and stems.
    d. Cleaning filters and replacing glass wool. (CAUTION: Glass wool soaked with liquid chlorine or chlorine impurities may burn your skin or give off sufficient chlorine gas to be dangerous.)
    e. Painting of equipment if needed.

7.451 Evaporators (Figure 7.28)

Evaporators are used to convert liquid chlorine to gaseous chlorine for use by gas chlorinators.

DAILY

1. Check evaporator water bath to be sure water level is at midpoint of sight glass.
2. In most evaporators the water bath temperature is between 160 to 195°F (71 to 91°C). Low alarm should sound at 160°F (71°C) and high alarm should sound at 200°F (93°C).
3. Determine chlorine inlet pressure to evaporator. Pressure should be same pressure as on supply manifold from containers (20 to 100 psi, 138 to 690 kPa or 1.4 to 7 kg/sq cm).
4. Measure chlorine outlet temperature from evaporator. Typical range is 90 to 105°F (32 to 41°C). High alarm should sound at 110°F (43°C). At low temperatures the chlorine pressure-reducing valve (CPRV) will close due to the low temperature in the water bath.

5. Check chlorine pressure-reducing valve (CPRV) for open-closed position.
6. If evaporator is equipped with water bath recirculation pump at back of evaporator, determine if pump is operating properly.
7. Look for leaks and repair any discovered.

ABNORMAL EVAPORATOR CONDITIONS

1. Evaporator water level low. Water level not visible in sight glass.

   Troubleshooting Measurements

   a. Determine actual level of of water.
   b. Measure temperature of water.
   c. Check temperature and pressure of chlorine in evaporator system and feed lines back to containers and chlorinators for possible overpressure of system (pressure should not exceed 100 psi, 690 kPa or 7 kg/sq cm).

   Corrective Action

   a. If chlorine pressure on system is near or over 100 psi (690 kPa or 7 kg/sq cm), close supply-container valves to stop chlorine addition to the system, increase feed rate of chlorinator to use chlorine in the system, and drop the pressure back down to a safe range. NOTE: Alarm system is usually set to sound at 110 psi (758 kPa or 7.7 kg/sq cm). If system pressure was at or over 110 psi (758 kPa or 7.7 kg/sq cm), inspect alarm circuit to determine failure of alarm.
   b. If temperature of water bath is set at an abnormal level, find the cause. Water bath levels are usually set in the following sequence:

      1) 160°F or 71°C: low temperature alarm.
      2) 185 to 195°F or 95 to 91°C: normal operating range.
      3) 185°F or 85°C: actuates pressure-reducing valve (PRV) to open position.
      4) 200°F or 93°F: high temperature alarm.

      If temperature is above 200°C (93°C), alarm should have sounded. Open control switch on evaporator heaters to stop current flow to heating elements. If temperature is in normal range, return to correcting the original problem of a low water level.
   c. Evaporator water levels are controlled by a solenoid valve. First check to see if drain valve is fully closed and then use the following steps:

      1) Override solenoid valve and fill water bath to proper level.
      2) If water cannot be added, take evaporator out of service:
         a) Try to remove all liquid chlorine left in line,
         b) Switch to another evaporator, or
         c) Switch supply to gas side of containers.

2. Low water temperature in evaporator.

   a. Check chemical (chlorine) flow-through rate. Rate may have exceeded unit's capacity and may require two evaporators to be on line to handle chemical feed rate.
   b. Inspect immersion heaters for proper operation. First examine control panel for thermal overload on breaker. Most evaporators are equipped with two to three heating elements. An inspection of the electrical system will indicate if the breakers are shorted or open and will locate the problem. Replace any heating elements that have failed.
   c. If no spare evaporators are available, operate from the valves on the chlorine gas supply. If necessary, reduce the chlorine feed rate to keep the chlorination system working properly.

3. No chlorine gas flow to the chlorinator.

   a. Inspect pressure-reducing valve downstream from evaporator and determine if valve is in the open or closed position.

      1) Valve may be closed due to low water temperature in evaporator (less than 185°F or 85°C).
      2) Valve may be closed due to loss of vacuum on system or loss of continuity of electrical control circuits which may have been caused by a momentary power drop. Correct problem and reset valve.
      3) Valve may be out of adjustment and restricting gas flow through the valve due to a low pressure setting.

   b. Inspect supply containers and manifold. Possible sources of lack of chlorine gas flow to chlorinators include:

      1) Containers empty.
      2) Container chlorine supply lines incorrectly connected to gas instead of liquid side of containers. High flow rates of gas will remove gas from container faster than it can change from liquid to gas. This will cause a reduced flow of chlorine gas. When this happens a frost may appear on valves and flex connectors. Reduce flow of water being treated and/or connect more chlorine containers.
         WARNING. When frost appears on valves and flex connectors, the chlorine gas may condense to liquid chlorine (reliquify). The liquid chlorine may plug the chlorine supply lines (sometimes this is referred to as chlorine ice or frozen chlorine). If you disconnect the chlorine supply line to unplug it, *BE VERY CAREFUL.* The liquid chlorine in the line could reevaporate, expand as a gas, build up pressure in the line, and cause liquid chlorine to come shooting out the open end of a disconnected chlorine supply line.
      3) Chlorine manifold filters plugged. Check pressure upstream and downstream from filter. Pressure drop should not exceed 10 psi (6.9 kPa or 0.7 kg/sq cm). Frost on manifold may indicate an excessive flow of chlorine gas through the filters.
      4) Inspect manifold and system for closed valves. Most systems operate properly with all chlorine valves at only ONE TURN OPEN position.

MONTHLY

1. Exercise all valves, including inlet, outlet, pressure reducing (PRV), water, drain and fill valves.
2. Inspect evaporator cathodic-protection meter (if so equipped). Cathodic protection protects the metal water tank and piping from corrosion due to electrolysis. Electrolysis is the flow of electrical current and is the reverse of metal plating. In electrolysis, the flow of certain compounds away from the metal causes corrosion and holes in a short time. This type of corrosion is controlled by either a sacrificial anode made of magnesium and zinc or by applying small electrical currents to suppress or reverse the normal corroding current flow.
3. Check setting of PRV (pressure-reducing valve) in order to maintain desired pressure of chlorine gas to chlorinators.

4. Inspect heating and ventilating equipment in chlorinator area.
5. Perform scheduled routine preventive maintenance.
    - a. Drain and flush water bath.
    - b. Clean evaporator tank.
    - c. Repack gasket and reseat pressure-reducing valves.
    - d. Check heater elements.
    - e. Replace anodes.
    - f. Paint system.

7.452 Chlorinators, Including Injectors

DAILY

1. Check injector water supply pressure. Pressures will range from 40 to 90 psi (276 to 520 kPa or 2.8 to 6.3 kg/sq cm) depending on system.
2. Determine injector vacuum. Values will range from 15 to 25 inches (38 to 64 cm) of mercury.
3. Check chlorinator vacuum. Values will range from 5 to 10 inches (13 to 25 cm) of mercury.
4. Determine chlorinator chlorine supply pressure. Values will range from 20 to 40 psi (138 to 276 kPa or 1.4 to 2.8 kg/sq cm) after the pressure regulating valve.
5. Read chlorinator feed rate on rotameter tube. Is feed rate at required level? Record rotameter reading and time.
6. Examine and record mode of control.
    - a. Manual
    - b. Automatic (single input)
    - c. Automatic (dual input)
7. Measure chlorine residual at application point.
8. Inspect system for chlorine leaks.
9. Inspect auxiliary components.
    - a. Flow signal input. Does chlorinator feed rate change when flow changes? Chlorinator response is normally checked by biasing (adjusting) flow signal which may drive dosage control unit on chlorinator to full open or closed position. When switch is released, chlorinator will return to previous feed rate. During this operation the unit should have responded smoothly through the change. If the response was not smooth, look for mechanical problems of binding, lubrication, or vacuum leaks.
    - b. If chlorinator also is controlled by a residual analyzer, be sure the analyzer is working properly. Check the following items on the residual analyzer. Be sure to follow the manufacturer's instructions.
        - 1) Actual chlorine residual is properly indicated.
        - 2) Recorder alarm set point.
        - 3) Recorder control set point.
        - 4) Sample water flow.
        - 5) Sample water flow to cell block after dilution with fresh water.
        - 6) Adequate flow of dilution water.
        - 7) Filter system and drain.
        - 8) Run comparison tests of chlorine residual. Do tests match with analyzer output readings?
        - 9) If residual analyzer samples two streams, start other stream flow and compare tested residual of that stream with analyzer output readings. Standardize analyzer output readings against tested residuals. Enter changes and corrections in log.
        - 10) Change recorder chart daily or as necessary.
        - 11) Check recorder output signal controlling chlorinator for control responses on feed rate. Correct feed rates through ratio controller.

WEEKLY

1. Put chlorinator on manual control. Operate feed-rate adjustment through full range from zero to full scale (250, 500, 1000, 2000, 4000, 6000, 8000, or 10,000 pounds/day). At each end of scale check:
    - a. Chlorinator vacuum.
    - b. Injector vacuum.
    - c. Solution line pressure.
    - d. Chlorine pressure at chlorinator.

    If any of the readings do not produce normal set points, make proper adjustments.

    - 1) Injector should produce necessary vacuum at chlorinator (5 to 10 inches or 13 to 25 centimeters of mercury).
    - 2) Adjust PRV to obtain sufficient pressure and chemical feed for full feed-rate operation of chlorinator.
2. If unit performs properly through complete range of feed rates, return unit to automatic control. If any problems develop, locate source and correct.
3. Clean chlorine residual analyzer (see Section 7.7, "Measurement of Chlorine Residual"), including the following items:
    - a. Clean filters.
    - b. Clean sample line.
    - c. Clean hydraulic dilution wells and baffles.
    - d. Flush discharge hoses and pipes.
    - e. Clean and flush cell block.
    - f. Fill buffer reservoirs.
    - g. Check buffer pump and feed rate.
    - h. Wipe machine clean and keep it clean.

MONTHLY

1. Exercise all chlorine valves.
2. Inspect heaters and room ventilation equipment.
3. Check chlorinator vent line to outside of structure for any obstructions that could prevent free access to the atmosphere. Bugs and wasps like vent lines for nests.
4. Inspect unit for vacuum leaks.
5. Clean rotameter sight glass.
6. Inspect all drain lines and hoses.
7. Perform scheduled routine maintenance.
    - a. Disassemble, clean and regasket chlorinator (once a year).
    - b. Repack seat and stem of valves.
    - c. Inspect tubing and fittings for leaks. Wash and dry thoroughly before reassembling.
    - d. Inspect control system.
        - 1) Electrical and electronics.
        - 2) Pneumatics.
        - 3) Lubrication.
        - 4) Calibration of total system.
    - e. Chlorine analyzer.
        - 1) Lubrication of chart drives, filter drives and pumps.

   2) Clean and flush all piping and hoses, filters, tubing, cell blocks and hydraulic chambers.
   3) Clean acid and iodide reservoirs.
   4) Calibrate unit with known standards.
   5) Repaint unit if needed.

f. Inspect safety equipment, including self-contained breathing equipment and repair kits.

POSSIBLE ABNORMAL CONDITIONS

1. Chlorine leak in chlorinator.

   Shut off gas flow to chlorinator. Leave injector on line. Allow chlorinator to operate and empty chlorine gas for three to five minutes with zero psi showing on the chlorine pressure gage. Repair leak or switch to another chlorinator and repair leak.

2. Gas pressure too low, less than 20 psi (138 kPa or 1.4 kg/sq cm). Alarm indicated. Check chlorine supply:

   a. Empty containers, switch to standby units.
   b. Evaporator shut down. See Section 7.451, "Evaporators."
   c. Inspect manifold for closed valves or restricted filters. Correct by switching to another manifold or setting valves and controls to proper position.

3. Injector vacuum too low.

   a. Adjust injector to achieve required vacuum.
   b. Inspect injector water supply system.

      1) Pump off: start pump.
      2) Strainers dirty: clean strainers.
      3) Pump worn out and will not deliver appropriate flow and pressure to injector: use other unit and/or repair or replace pump.

   c. Inspect solution line discharge downstream from injector. Check for the following items:

      1) Valve closed or partially closed.
      2) Line broken or restriction reducing flow or increasing back pressure.
      3) Diffuser plugged, thus restricting flow and creating a higher back pressure on discharge line and injector. Clean diffuser and flush pipe.

4. Low chlorine residual. Alarm indicator is on from chlorine residual analyzer.

   Determine actual chlorine residual and compare with residual reading from chlorine analyzer. If residual analyzer is off, recalibrate analyzer and readjust. If chlorine residual analyzer is correct and chlorine residual is low, check the following items:

   a. Sample pump

      1) Operation, flow and pressure.
      2) Sample lines clean and free of solids or algae that could create a chlorine demand.
      3) Strainer dirty and restricting flow, thus preventing adequate pressure (15 to 20 psi, 103 to 138 kPa, or 1.0 to 1.4 kg/sq cm) at analyzer.

   b. Control system if chlorinator is on automatic control. If chlorine feed rate remains too low, take chlorinator off of automatic control and switch to manual control. Set chlorinator to proper feed rate as determined by previous adequate feed rates.
   c. Chlorine demand higher than the amount one chlorinator can supply. Place additional chlorinator on line.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.4P Normal operation of a chlorinator includes daily inspection of what facilities or areas?

7.4Q What is the purpose of evaporators?

7.4R What abnormal conditions could be encountered when operating an evaporator?

7.4S How can you determine if chlorine residual analyzer is working properly?

7.4T What are possible chlorinator abnormal conditions?

7.453 Summary, Daily Operation

Actual procedures for operating chlorination equipment will vary from plant to plant, region to region, season to season and water to water. The following procedures are provided to serve as guidelines to help you develop your own procedures.

1. *PRECHLORINATION*
   If trihalomethanes are not a problem, prechlorination is a very cost-effective means of disinfecting water. Prechlorination should be at a chlorine dosage that will produce a free chlorine residual (past the breakpoint) of between 0.5 to 1.5 mg/*L* before the flocculation basins. If trihalomethanes are a problem, see Chapter 15, "Trihalomethanes." If phenolic compounds are present, discontinue prechlorination, adsorb phenols with activated carbon and remove by filtration, and disinfect by postchlorination.

2. *POSTCHLORINATION*
   Regardless of whether prechlorination is practiced or not, a free chlorine residual of at least 0.5 mg/*L* should be maintained in the clear well or distribution reservoir immediately downstream from the point of postchlorination.

3. *DISTRIBUTION SYSTEM*
   Postchlorination dosages should be adequate to produce a free chlorine residual of 0.2 mg/*L* at the farthest point in the distribution system at all times.

Very often when consumers complain about chlorine tastes in their drinking water, the chlorine dose has been *INADEQUATE*. When the chlorine dose is inadequate, the measured chlorine residual is frequently combined available chlorine. By increasing the chlorine dose, you chlorinate past the breakpoint and the chlorine residual may be lower, but the residual contains free available chlorine. One way to determine if you have reached the chlorine breakpoint is to increase the chlorine dose rate. If the residual chlorine increases in proportion to the increased dose, then you are chlorinating past the breakpoint. For a discussion of breakpoint chlorination, see Section 7.25, "Breakpoint Chlorination."

The objective of disinfection is the destruction of pathogenic organisms, and the ultimate measure of the effectiveness is the bacteriological result (negative coliform test results). The measurement of chlorine residual does supply a tool for practical control. If the chlorine residual value commonly effective in most water treatment plants does not yield satisfactory bacteriological kills in a particular plant, the residual chlorine that does produce satisfactory results must be determined and used as a control in that plant. In other words, the 0.5 mg/*L* chlorine residual, while generally effective, is not a rigid standard but a guide that may be changed to meet local requirements.

FORMULA

To determine if the chlorinator setting is high enough to produce a free available residual chlorine past the breakpoint, we can increase the chlorinator feed rate. If all of the chlorine fed at the new or higher setting is converted to chlorine residual in milligrams per liter, we know that the original setting was at or past the breakpoint. The expected increase in chlorine residual can be calculated by using the formula:

$$\text{Expected Increase in Residual, mg}/L = \frac{\text{New Setting, lbs/day} - \text{Old Setting, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

To determine the actual increase in free chlorine residual, find the difference in milligrams per liter between the new and old free available residual chlorine.

$$\text{Actual Increase, mg}/L = \text{New Residual, mg}/L - \text{Old Residual, mg}/L$$

EXAMPLE 4

A chlorinator is set to feed chlorine to a treated water at a dose of 27 pounds of chlorine per 24 hours. This dose rate produces a free chlorine residual of 0.4 mg/*L*. When the chlorinator setting is increased to 30 pounds per 24 hours, the free chlorine residual increases to 0.6 mg/*L*. If the average 24-hour flow is 1.6 MGD, is the water being chlorinated past the breakpoint?

Known		Unknown
Old Setting, lbs/day	= 27 lbs/day	1. Increase in Residual, mg/*L*
New Setting, lbs/day	= 30 lbs/day	2. Past Breakpoint?
Old Residual, mg/*L*	= 0.4 mg/*L*	
New Residual, mg/*L*	= 0.6 mg/*L*	
Flow, MGD	= 1.6 MGD	

1. Calculate the expected increase in chlorine residual if chlorination is at the breakpoint.

$$\begin{aligned}\text{Expected Increase in Residual, mg}/L &= \frac{\text{New Setting, lbs/day} - \text{Old Setting, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}\\ &= \frac{(30\text{ lbs/day} - 27\text{ lbs/day})}{(1.6\text{ MGD})(8.34\text{ lbs/gal})}\\ &= 0.2\text{ mg}/L\end{aligned}$$

2. Determine actual increase in free chlorine residual in mg/*L*.

$$\begin{aligned}\text{Actual increase, mg}/L &= \text{New Residual, mg}/L - \text{Old residual, mg}/L\\ &= 0.6\text{ mg}/L - 0.4\text{ mg}/L\\ &= 0.2\text{ mg}/L\end{aligned}$$

3. Is the water being chlorinated past the breakpoint? Yes, since the calculated expected increase in chlorine residual (0.2 mg/*L*) is approximately the same as the actual increase in the chlorine residual (0.2 mg/*L*), we can conclude that we are chlorinating past the breakpoint.

7.46 Troubleshooting Gas Chlorinator Systems

OPERATING SYMPTOMS	PROBABLE CAUSE	REMEDY
1. Injector vacuum reading low	Hydraulic system	Check injector water supply system
	Flow restricted	Adjust injector orifice
	Low pressure	Close throat
	High pressure	Open throat
	Back pressure	Change injector and/or increase water supply to injector
	Low flow of water	Increase pump output
2. Leaking joints	Missing gasket	Repair joint
3. Chlorinator will not reach maximum point	Faulty injector (no vacuum)	Repair injector system
	Restriction in supply	Find restriction in supply system
	Faulty chlorinator	Check for vacuum leaks
	Leaks	Repair leaks
	Wrong orifice	Install proper orifice

7.46 Troubleshooting Gas Chlorinator Systems (Continued)

OPERATING SYMPTOMS	PROBABLE CAUSE	REMEDY
4. Chlorinator will feed OK at maximum output, but will not control at low rates	Vacuum regulating valve	Repair diaphragm
		Check valve capsule
	If equipped with CPRV (Chlorine Pressure Reducing Valve)	Clean CPRV cartridge, CPRV diaphragm, and CPRV gaskets
5. Chlorinator does not feed	Supply	Renew Cl_2 supply
	Piping	Open valve
		Clean filter
6. Variable vacuum control, formerly working well, now will not go below 30% feed. Signal OK	CPRV	Clean CPRV
7. Variable vacuum control reaches full feed, but will not go below 50% feed. CPRV OK	Signal vacuum too high	Hole in diaphragm
		Clean dirty filter disks
		Clean converter nozzle
8. Variable vacuum control won't go to full feed. Gas pressure OK. CPRV OK	Plugged restrictor	Clean restrictor
	Air leak in signal	Repair air leak
9. Freezing of manometer	Rate too high	Lower rate
	Restriction in manometer orifice	Clean piping

7.47 Chlorination System Failure

IF YOUR CHLORINATION SYSTEM FAILS, DO NOT ALLOW UNCHLORINATED WATER TO ENTER THE DISTRIBUTION SYSTEM. Never allow unchlorinated water to be delivered to your consumers. If your chlorination system fails and cannot be repaired within a reasonable time period, notify your supervisor and officials of the health department. To prevent this problem from occurring, your plant should have back up or standby chlorination facilities.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.4U What is the suggested free chlorine residual for treated water (measured at a point just beyond postchlorination)?

7.4V What is the suggested free chlorine residual for the farthest point in the distribution system?

7.4W How would you determine if you were chlorinating at the breakpoint?

DISCUSSION AND REVIEW QUESTIONS

CHAPTER 7. DISINFECTION

(Lesson 2 of 3 Lessons)

Write the answers to these questions in your notebook before continuing. The problem numbering continues from Lesson 1.

6. Why should precautions be taken to avoid sharp bends in copper tubing used to convey chlorine?
7. How should valves on chlorine containers be opened?
8. What should be done to the water supply pump when the hypochlorinator is shut down?
9. Why must liquid chlorine piping systems be dry?
10. Why should chlorine containers and cylinders be stored where they won't be heated?
11. What are the advantages and limitations of prechlorination?

End of Lesson 2 of 3 Lessons on DISINFECTION

CHAPTER 7. DISINFECTION

(Lesson 3 of 3 Lessons)

7.5 MAINTENANCE

Necessary maintenance of chlorination equipment requires a thorough understanding of the manufacturer's literature. Generally the daily, weekly and monthly operating procedures also contain the appropriate maintenance procedures. Do not attempt maintenance tasks which you are not qualified to perform. There are too many possibilities for serious accidents when you are not qualified.

7.50 Hypochlorinators

See Section 7.440, Hypochlorinators, 3. Normal Operation of Hypochlorinators (page 293) and 5. Maintenance of Hypochlorinators (page 295).

7.51 Chlorinators

See Section 7.441, Chlorinators, (page 296) and 7.45, Normal and Abnormal Operation (page 298).

7.52 Chlorine Leaks

Your sense of smell can detect chlorine concentrations as low as 4 ppm. Portable and permanent automatic chlorine detection devices (Figure 7.29) can detect chlorine concentrations of 1 ppm or less. Whenever you must deal with a chlorine leak, always follow the safe procedures outlined in Section 7.8, "Chlorine Safety Program."

CHLORINE LEAKS MUST BE TAKEN CARE OF IMMEDIATELY OR THEY WILL BECOME WORSE. Corrective measures should be undertaken only by trained operators wearing proper safety equipment. All operators should be trained to repair chlorine leaks. Always work in pairs when looking for and repairing leaks. All other persons should leave the danger area during repairs until conditions are safe again.

If the leak is large, all persons in the adjacent areas should be warned and evacuated. Obtain help from your fire department. They have self-contained breathing equipment and can help evacuate people. The police department can help control curious sightseers. Repair crews and drivers of emergency vehicles must realize that vehicle engines will quit operating in the vicinity of a large chlorine leak because of lack of oxygen. You must always consider your neighbors . . . PEOPLE, animals, and plants.

1. *BEFORE ANY NEW SYSTEM IS PUT INTO SERVICE,* it should be cleaned, dried, and tested for leaks. Clean and dry pipelines by flushing and steaming from the high end to allow condensate and foreign materials to drain out. After the empty line is heated thoroughly, blow dry air through the line until it is dry. After drying test the system for tightness with 150 psi (1034 kPa or 10.5 kg/sq cm) dry air. Apply soapy water to the outside of joints to detect leaks. Small quantities of chlorine gas may now be introduced into the line, the test pressure built up with air, and the system tested for leaks. Whenever a new system is tested for leaks, at least one chlorinator should be on the line to withdraw chlorine from the system in case of a leak. The same is true in case of an emergency leak at any installation. If a chlorinator is not running, at least one or more should be started. Preferably, all available chlorinators should be put on the line.

2. *TO FIND A CHLORINE LEAK,* tie a rag on a stick, *DIP THE RAG*[28] in a strong ammonia solution,[29] and hold the rag near the suspected points. White fumes will indicate the exact location of the leak. Location of leaks by this method may not be possible for large leaks which diffuse the gas over large areas. Do not use an ammonia spray bottle because the entire room could turn white if it is full of chlorine gas. Also any chlorine deposits will draw water from the ammonia and form an acid which will eat away any material it contacts.

3. *IF THE LEAK IS IN THE EQUIPMENT* in which the chlorine is being used, close the valves on the chlorine container at once. Repairs should not be attempted while the equipment is in service. All chlorine piping and equipment that is to be repaired by welding should be flushed with water or steam. Before returning equipment to use, it MUST be cleaned, dried, and tested as previously described.

4. *IF THE LEAK IS IN A CHLORINE CYLINDER OR CONTAINER,* use the emergency repair kit supplied by most chlorine suppliers (Figure 7.30). These kits can be used to stop most leaks in a chlorine cylinder or container and can usually be delivered to a plant within a few hours if one is not already at the site of the leak. *IT IS ADVISABLE TO HAVE EMERGENCY REPAIR KITS AVAILABLE AT YOUR PLANT AT ALL TIMES AND TO TRAIN PERSONNEL FREQUENTLY IN THEIR USE.* Location of such kits should be posted outside chlorine storage areas. Refer to Figure 7.17 in Section 7.421, "Steel Cylinders," for typical locations of cylinder valve leaks.

5. If chlorine is escaping as a liquid from a cylinder or a ton tank, turn the container so that the leaking side is on top. In this position, the chlorine will escape only as a gas, and the amount which escapes will be only 1/15 as

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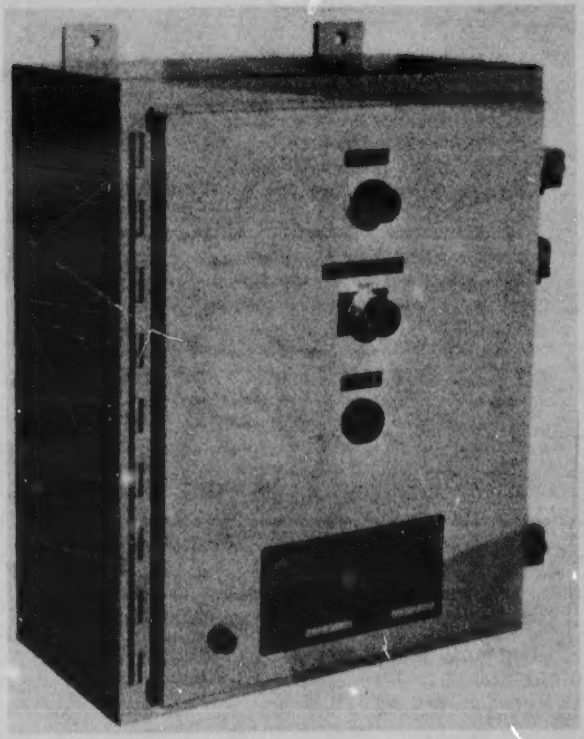
[28] *A one-inch (2.5 cm) paint brush may be used instead of a rag.*

[29] *Use a concentrated ammonia solution containing 28 to 30 percent ammonia as NH_3 (this is the same as 58 percent ammonium hydroxide, NH_4OH, or commercial 26° Baume).*

Portable Chlorine Leak Detector

(Permission of Leak-Tec Division American Gas & Chemical Co., Ltd.)



Audio-Visual Chlorine Alarm Panel

(Permission of Chlor-O-Quip, a Division of Filtronics, Inc.)

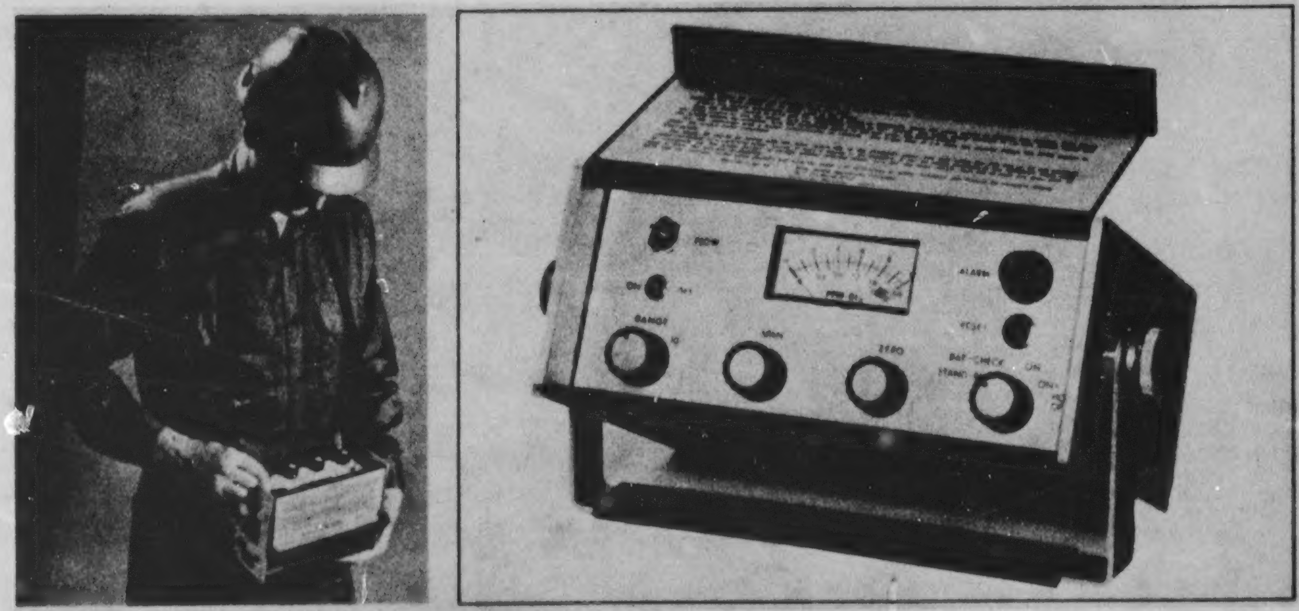
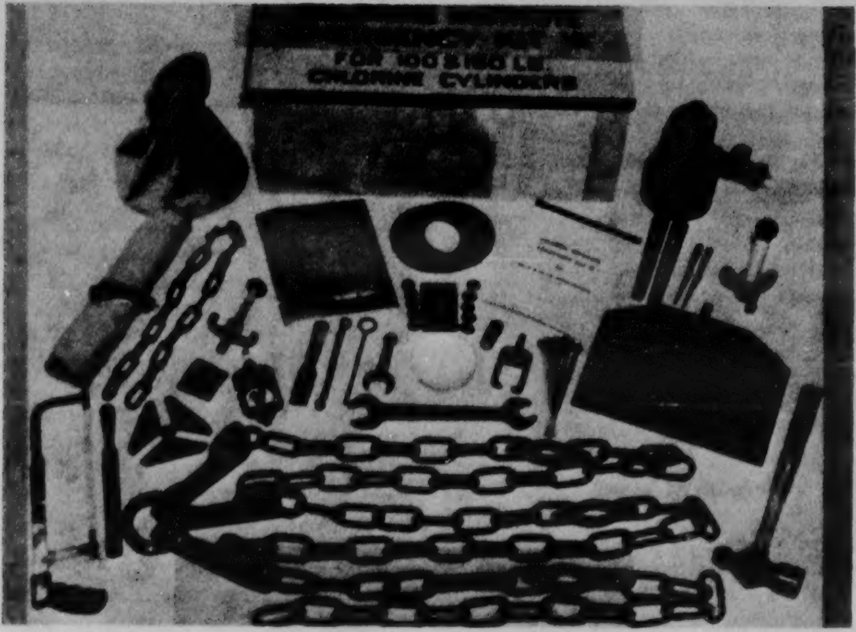
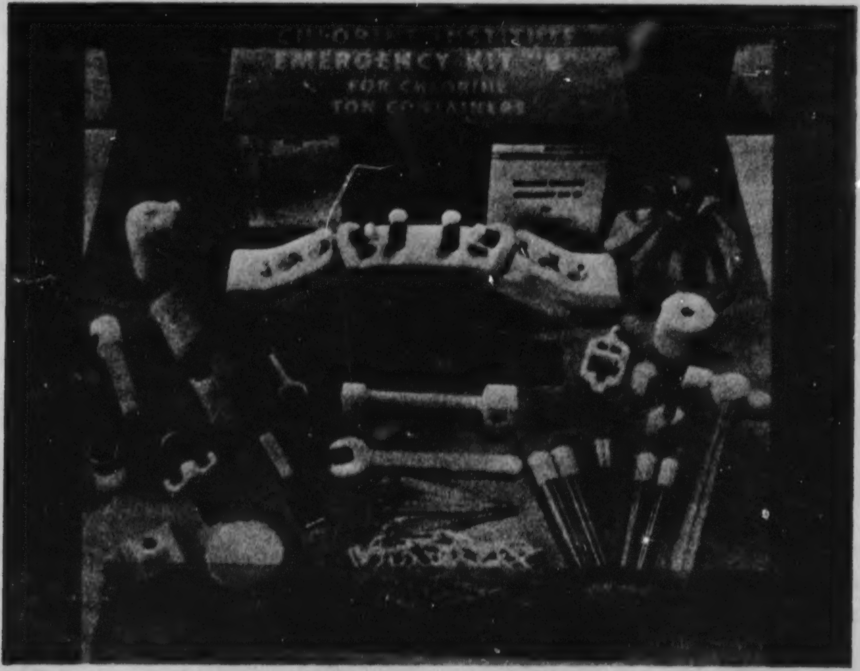

RANGE
ZERO
ALARM
RESET
BAT-CHECK
ON

Fig. 7.29 Chlorine leak detectors

(Permission of MSA, Mine Safety Appliances Company)


FOR 100 & 150 LB
CHLORINE CYLINDERS

Emergency Kit "A" for Chlorine Cylinders


CHLORINE INSTITUTE
EMERGENCY KIT "B"
FOR CHLORINE
TON CONTAINERS

Emergency Kit "B" for Chlorine Ton Containers

Fig. 7.30 Chlorine Institute Emergency Repair Kits

(Permission of the Chlorine Institute, Inc.)

much as if the liquid chlorine were leaking. Keeping the chlorinators running also will reduce the amount of chlorine gas leaking out of a container. Increase the feed rate to cool the supply tanks as much as possible.

6. *FOR SITUATIONS IN WHICH A PROLONGED OR UNSTOPPABLE LEAK* is encountered, emergency disposal of chlorine should be provided. Chlorine may be absorbed in solutions of caustic soda (sodium hydroxide), soda ash (sodium carbonate), or agitated hydrated lime (calcium hydroxide) slurries (Table 7.5). Chlorine should be passed into the solution through an iron pipe or a properly weighted rubber hose to keep it immersed in the absorption solution. The container should not be immersed because the leaks will be aggravated due to the corrosive effect, and the container may float when partially empty. In some cases it may be advisable to move the container to an isolated area. Discuss the details of such precautions with your chlorine supplier.
7. *NEVER PUT WATER ON A CHLORINE LEAK.* A mixture of water and chlorine will increase the rate of corrosion of the container and make the leak larger. Besides, water may warm the chlorine, thus increasing the pressure and forcing the chlorine to escape faster.
8. *LEAKS AROUND VALVE STEMS* can often be stopped by closing the valve or tightening the packing gland nut. Tighten the nut or stem by turning it clockwise.
9. *LEAKS AT THE VALVE DISCHARGE OUTLET* can often be stopped by replacing the gasket or adapter connection.
10. *LEAKS AT FUSIBLE PLUGS AND CYLINDER VALVES* usually require special handling and emergency equipment. Call your chlorine supplier immediately and obtain an emergency repair kit for this purpose if you do not have a kit readily available.
11. *PIN HOLE LEAKS* in the walls of cylinder and ton tanks can be stopped by using a clamping pressure saddle with a turn-buckle available in repair kits. This is only a temporary measure, and the container must be emptied as soon as possible.

    If a repair kit is not available, use your ingenuity. One operator stopped a pin hole leak temporarily until a repair kit arrived by placing several folded layers of neoprene packing over a leak, a piece of scrap steel plate over the packing, wrapping a chain around the cylinder and steel plate, and applying leverage pressure with a crowbar.

    Dry ice has been applied to chlorine containers to cool the liquid and thus reduce the amount of gas escaping through a pin hole leak.
12. *A LEAKING CONTAINER* must not be shipped. If the container leaks or if the valves do not work properly, keep the container until you receive instructions from your chlorine supplier for returning it. If a chlorine leak develops in transit, keep the vehicle moving until it reaches an open area.
13. Do not accept delivery of containers showing evidence of leaking, stripped threads, or abuse of any kind.
14. If a chlorine container develops a leak, be sure your supplier does not charge you for the unused chlorine.
15. Chlorine leaks may be detected by sniffleators and other detection devices (Figure 7.29). Alarm systems may be connected to these devices. Be sure to follow the manufacturer's recommendations regarding frequency of checking and testing detection devices and alarm systems.

TABLE 7.5 CHLORINE ABSORPTION SOLUTIONS[a]

Absorption Solution		Chemical (lb)	Water (gal)
Caustic Soda (100%)	a	125	40
(Sodium Hydroxide)	b	188	60
	c	2500	800
Soda Ash	a	300	100
(Sodium Carbonate)	b	450	150
	c	6000	2000
Hydrated Lime[b]	a	125	125
(Calcium Hydroxide)	b	188	188
	c	2500	2500

Chlorine Container Size (lb net):
a = 100, b = 150, c = 2000

[a] Source: The Chlorine Institute, Inc.

[b] Hydrated lime solution must be continuously and vigorously agitated while chlorine is to be absorbed.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.5A If chlorine is escaping from a cylinder, what would you do?

7.5B How can chlorine leaks around valve stems be stopped?

7.5C How can chlorine leaks at the valve discharge outlet be stopped?

7.53 Installation

The following are some features of importance when working with chlorine facilities. Also examine these items when reviewing plans and specifications.

1. Chlorinators should be located as near the point of application as possible.
2. There must be a separate room for chlorinators and chlorine container storage (above ground) to prevent chlorine gas leaks from damaging equipment and harming personnel. There should be no access to this room from a room containing equipment or where personnel work.
3. Ample working space around the equipment and storage space for spare parts should be provided.
4. There should be an ample supply of water to operate the chlorinator at required capacity under maximum pressure conditions at the chlorinator injector discharge.
5. The building should be adequately heated. The temperature of the chlorine cylinder and chlorinator should be above 50°F (10°C). Line heaters may be used to keep chlorine piping and chlorinator at higher temperatures to prevent condensing of gas into liquid in the pipelines and chlorinator. The maximum temperature at which a chlorine cylinder is stored shoud not exceed 100°F (43°C).

6. It is not advisable to draw more than 40 pounds (18 kg) of chlorine from any one 100- to 150-pound (45 and 68 kg) cylinder in a 24-hour period. At higher chlorine withdrawal rates, the chlorine gas is removed from the cylinder faster than the liquid chlorine is being converted to chlorine gas. When this happens the actual flow of chlorine gas will be reduced and become less than the desired rate. The maximum allowable chlorine withdrawal rate varies with temperature with the maximum withdrawal rate increasing as the temperature increases. With ton containers, the limit of chlorine gas withdrawal is about eight pounds of chlorine per day per °F (6.4 kg/°C) *AMBIENT TEMPERATURE.*[30] When evaporators are provided, these limitations do not apply.[31]
7. There should be adequate light.
8. There must be adequate ventilation. Continuous ventilation is desirable. Forced ventilation must be provided to remove gas if a large leak develops. The outlet of a forced ventilation system must be near the floor because chlorine is 2.5 times heavier than air. Use a pressurized fan (keep room under slight positive pressure). Do not suck air from room through the fan, because chlorine gas can damage the fan motor. Louvers or vents should swing out and always be open, or open automatically. It should be impossible to lock the louvers shut.
9. Adquate measuring and controlling of chlorine dosage is required. Scales and recorders indicating loss in weight are desirable as a continuous check and as a record of the continuity of chlorination. RECORD weights daily. Compare actual weight of chlorine used with calculated use based on chlorinator setting. Also compare results of chlorine residual tests with calculated dosage.
10. There should be continuity of chlorination. When chlorination is practiced for disinfection, it is needed continuously when the plant is operating for the protection of the water consumers. To insure continuous chlorination, the chlorine gas lines from cylinders should feed to the manifold so that the cylinders can be removed without interrupting the feed of gas. Duplicate units with automatic cylinder switchover should be provided. Hypochlorinators are sometimes used during emergencies.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.5D Why should chlorinators be located in a separate room?

7.5E How often should the weights of chlorine containers be recorded?

7.5F Why is adequate ventilation important in a chlorinator room?

7.5G How can chlorination rates be checked against the chlorinator setting?

7.6 CHLORINE DIOXIDE FACILITIES (FIGURES 7.31 and 7.32)

Use of chlorine dioxide as a disinfecting chemical instead of chlorine is of considerable interest to operators. A major reason for this interest is the fact that trihalomethanes are not formed when disinfecting with chlorine dioxide. Other reasons for considering chlorine dioxide include the fact that chlorine dioxide is effective in killing bacteria and viruses. Chlorine dioxide is much more effective than chlorine in killing bacteria in the pH range from 8 to 10. Chlorine dioxide does not combine with ammonia, and is more selective in its reaction with many organics than chlorine, therefore less chlorine dioxide is required to achieve equivalent chlorine residuals and bacteria kills in waters containing such contaminants.

Most existing chlorination units may be used to produce chlorine dioxide. In addition to the existing chlorination system, a diaphragm pump, solution tank, mixer, chlorine dioxide generating tower and electrical controls are needed. The diaphragm pump and piping must be made of corrosion-resistant materials because of the corrosive nature of chlorine dioxide. Usually, PVC or polyethylene pipe is used.

Special precautions must be taken when handling sodium chlorite. Sodium chlorite is usually supplied as a salt and is very combustible around organic compounds. Whenever spills occur, sodium chlorite must be neutralized with anhydrous sodium sulfite. Combustible materials (including gloves) should not be worn when handling sodium chlorite. If sodium chlorite comes in contact with clothing, the clothes should be removed immediately and soaked in water to remove all traces of sodium chlorite or they should be burned immediately. If you follow safe procedures, you can safely handle sodium chlorite. Chlorine dioxide has not been widely used to treat drinking water because of higher costs than other more commonly used disinfection methods.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.6A What additional equipment is necessary to use an existing chlorination unit to produce chlorine dioxide?

7.6B What hazards are associated with the handling of sodium chlorite?

7.7 MEASUREMENT OF CHLORINE RESIDUAL

7.70 Methods of Measuring Chlorine Residual

AMPEROMETRIC TITRATION[32] provides for the most convenient and most repeatable chlorine residual results. However, amperometric titration equipment is more expensive than equipment for other methods. *DPD TESTS*[33] can

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[30] *Ambient Temperature (AM-bee-ent). Temperature of the surrounding air (or other medium). For example, temperature of the room where a chlorinator is installed.*

[31] *For procedures on how to calculate maximum withdrawal rates, see "Maximum Withdrawal Rates from Chlorine, Sulfur Dioxide, and Ammonia Cylinders," by Robert J. Baker in the April, 1980, issue of OPFLOW, published by AWWA.*

[32] *Amperometric Titration (am-PURR-o-MET-rick). A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction.*

[33] *DPD Tests. A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N, N-diethyl-p-phenylenediamine.*

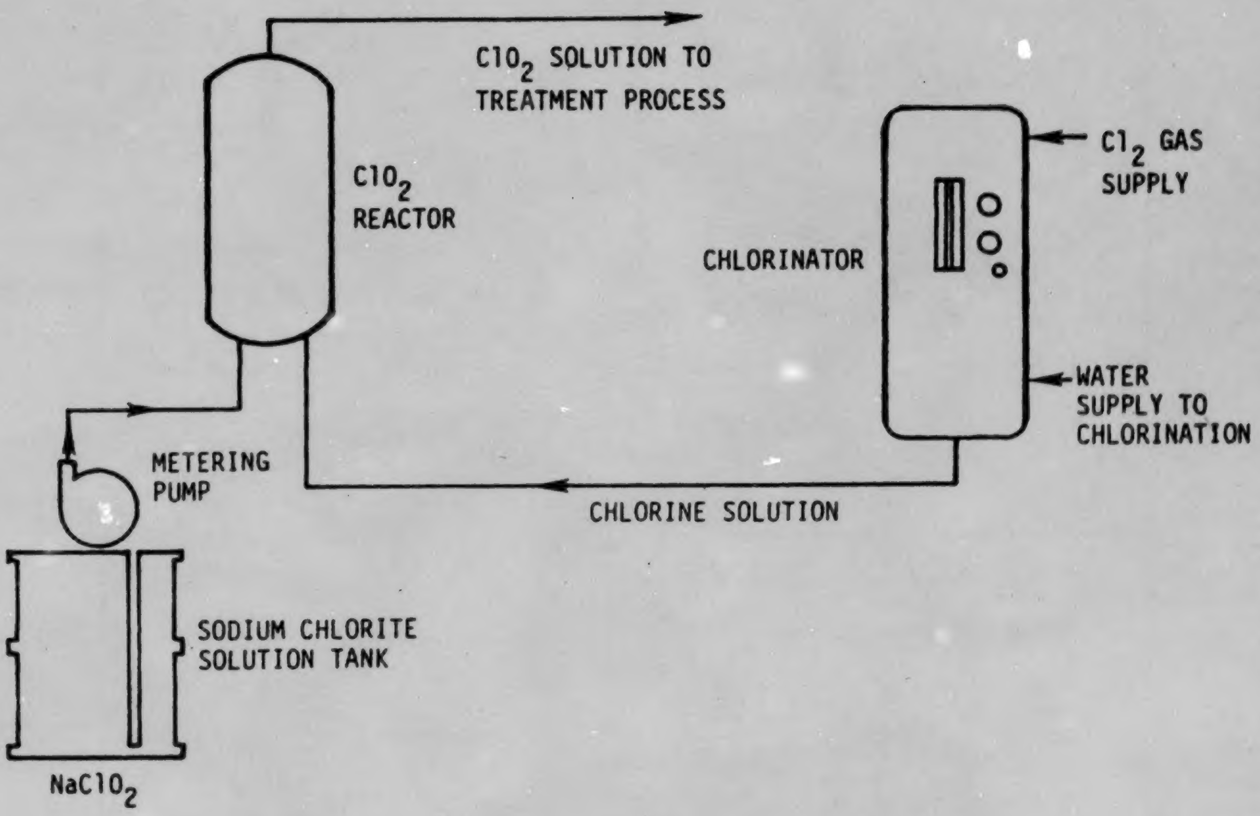
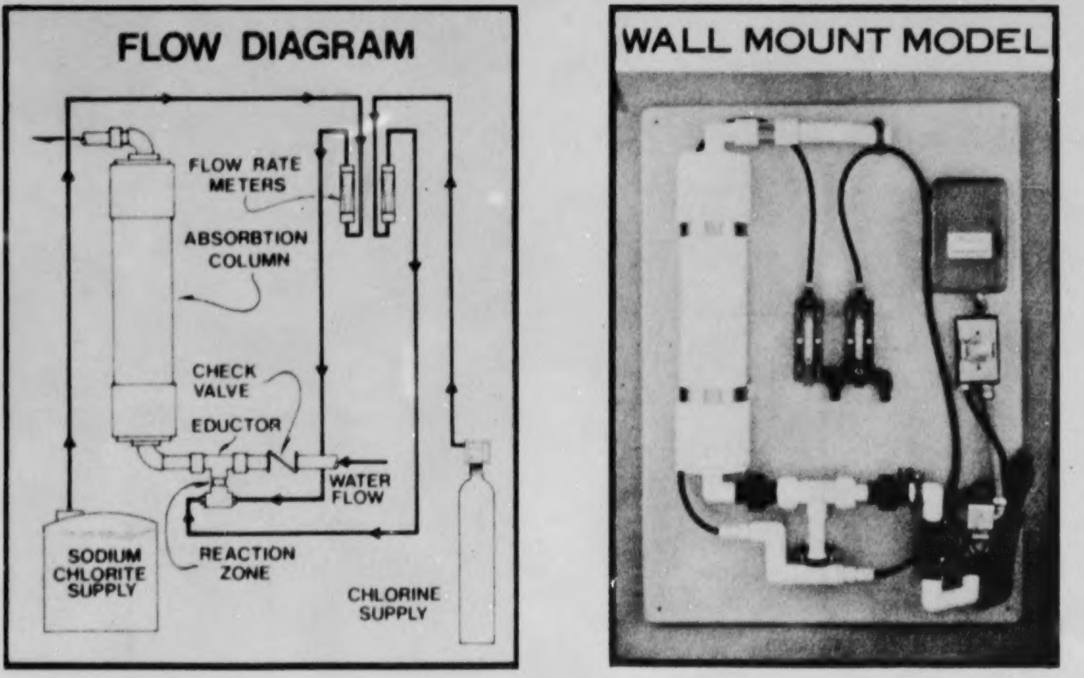
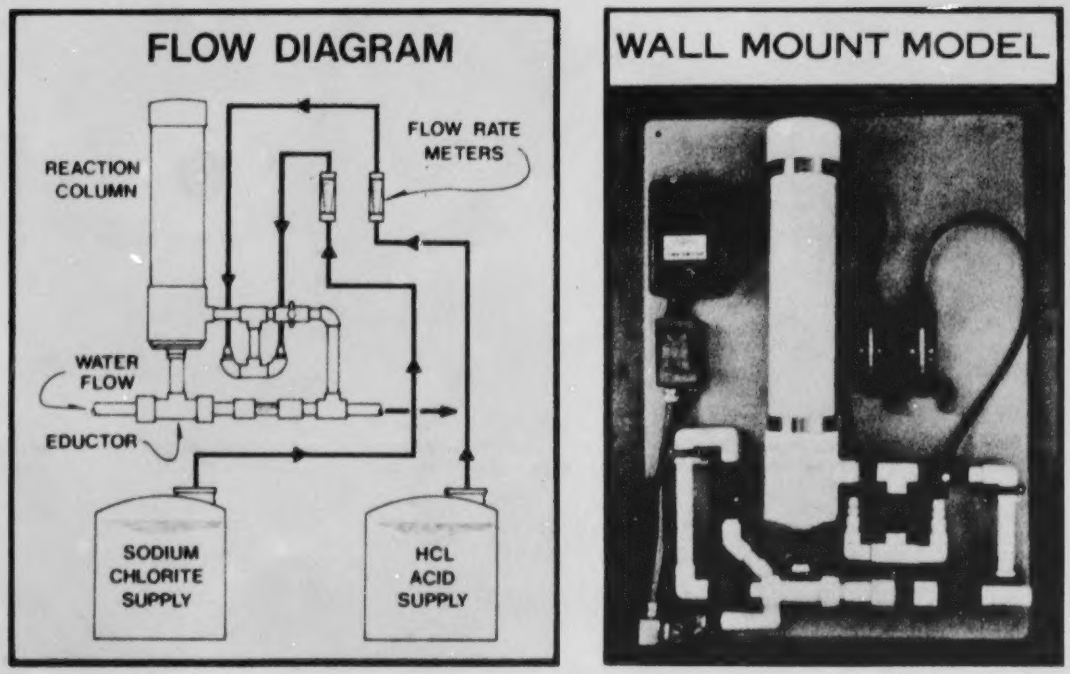

ClO_2 SOLUTION TO TREATMENT PROCESS
ClO_2 REACTOR
CHLORINATOR
Cl_2 GAS SUPPLY
WATER SUPPLY TO CHLORINATION
METERING PUMP
CHLORINE SOLUTION
SODIUM CHLORITE SOLUTION TANK
$NaClO_2$

Fig. 7.31 Chlorine dioxide facility

(Source: *AN ASSESSMENT OF OZONE AND CHLORINE DIOXIDE TECHNOLOGIES FOR TREATMENT OF MUNICIPAL WATER SUPPLIES, EXECUTIVE SUMMARY.* U.S. Environmental Protection Agency, Cincinnati, Ohio 45268, EPA-600/8-78-018, October 1978)


FLOW DIAGRAM
FLOW RATE METERS
ABSORBTION COLUMN
CHECK VALVE
EDUCTOR
WATER FLOW
SODIUM CHLORITE SUPPLY
REACTION ZONE
CHLORINE SUPPLY
WALL MOUNT MODEL

Chlorine-Chlorite Process (see Fig. 7.31)


FLOW DIAGRAM
FLOW RATE METERS
REACTION COLUMN
WATER FLOW
EDUCTOR
SODIUM CHLORITE SUPPLY
HCL ACID SUPPLY
WALL MOUNT MODEL

Acid-Chlorite Process

Fig. 7.32 Methods of generating chlorine dioxide

(Permission of Rio Linda Chemical Company) be used and are less expensive than other methods, but this method requires the operator to match the color of a sample with the colors on a comparator. See Chapter 11, "Laboratory Procedures," for detailed information on these tests.

Residual chlorine measurements of treated water should be taken at least three times per day on small systems and once every two hours on large systems. Residuals are measured to insure that the treated water is being adequately disinfected. A free chlorine residual of at least 0.5 mg/*L* in the treated water is usually recommended.

7.71 Amperometric Titration for Free Residual Chlorine

1. Place a 200 m*L* sample of water in the titrator.
2. Start the agitator.
3. Add 1 m*L* of pH 7 buffer.
4. Titrate with 0.00564 *N* phenylarsene oxide solution.
5. End point is reached when one drop will cause a deflection on the microammeter and the deflection will remain.
6. m*L* of phenylarsene oxide used in titration is equal to mg/*L* of free chlorine residual.

7.72 DPD Colorimetric Method for Free Residual Chlorine (Figures 7.34 and 7.35)

This procedure is for the use of prepared powder pillows.

1. Collect a 100 m*L* sample.
2. Add color reagent.
3. Match color sample with a color on the comparator to obtain the chlorine residual in mg/*L*.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.7A What two methods are commonly used to measure chlorine residual in treated water?

7.7B How often should treated water residual chlorine measurements be made?

7.8 CHLORINE SAFETY PROGRAM

Every good safety program begins with cooperation between the employee and the employer. The employee must take an active part in the overall program. The employee must be responsible and should take all necessary steps to prevent accidents. This begins with the attitude that as good an effort as possible must be made by everyone. Safety is everyone's problem. The employer also must take an active part by supporting safety programs. There must be funding to purchase equipment and to enforce safety regulations required by OSHA and state industrial safety programs. The following items should be included in all safety programs.

1. Establishment of a formal safety program.
2. Written rules.
3. Periodic hands-on training using safety equipment.
   a. Leak-detection equipment
   b. Self-contained breathing apparatus (Figure 7.25)
   c. Atmospheric monitoring devices
4. Establishment of emergency procedures for chlorine leaks and first aid.
5. Establishment of a maintenance and calibration program for safety devices and equipment.
6. Provide police and fire departments with tours of facilities to locate hazardous areas and provide chlorine safety information.

All persons handling chlorine should be thoroughly aware of its hazardous properties. Personnel should know the location and use of the various pieces of protective equipment and be instructed in safety procedures. In addition, an emergency procedure should be established and each individual should be instructed how to follow the procedures. An emergency checklist also should be developed and available. For additional information on this topic, see the Chlorine Institute's *CHLORINE MANUAL*, 4th Edition.[34] Also see Chapter 20, "Safety."

7.80 Chlorine Hazards

Chlorine is a gas, heavier than air, extremely toxic and corrosive in moist atmospheres. Dry chlorine gas can be safely handled in steel containers and piping, but with moisture must be handled in corrosion-resisting materials such as silver, glass, teflon, and certain other plastics. Chlorine gas at container pressure should never be piped in silver, glass, teflon, or any other material that cannot handle the pressure. Even in dry atmospheres, the gas is very irritating to the mucous membranes of the nose, to the throat, and to the lungs; a very small percentage in the air causes severe coughing. Heavy exposure can be fatal (see Table 7.6).

TABLE 7.6 PHYSIOLOGICAL RESPONSE TO CONCENTRATIONS OF CHLORINE GAS[a]

Effect	Parts of Chlorine Gas Per Million Parts of Air by Volume (ppm)
Slight symptoms after several hours' exposure	1
Detectable odor	3
60-minute inhalation without serious effects	4
Noxiousness	5
Throat irritation	15
Coughing	30
Dangerous from one-half to one hour	40
Death after a few deep breaths	1000

[a] Adapted from data in U.S. Bureau of Mines TECHNICAL PAPER 248 (1955).

WARNING

WHEN ENTERING A ROOM THAT MAY CONTAIN CHLORINE GAS, OPEN THE DOOR SLIGHTLY AND CHECK FOR THE SMELL OF CHLORINE. **NEVER** GO INTO A ROOM CONTAINING CHLORINE GAS WITH HARMFUL CONCENTRATIONS IN THE AIR WITHOUT A SELF-CONTAINED AIR SUPPLY, PROTECTIVE CLOTHING AND HELP STANDING BY. HELP MAY BE OBTAINED FROM YOUR CHLORINE SUPPLIER AND YOUR LOCAL FIRE DEPARTMENT.

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[34] *Write to: The Chlorine Institute, Inc., 342 Madison Avenue, New York, New York 10017. Price $5.00.*

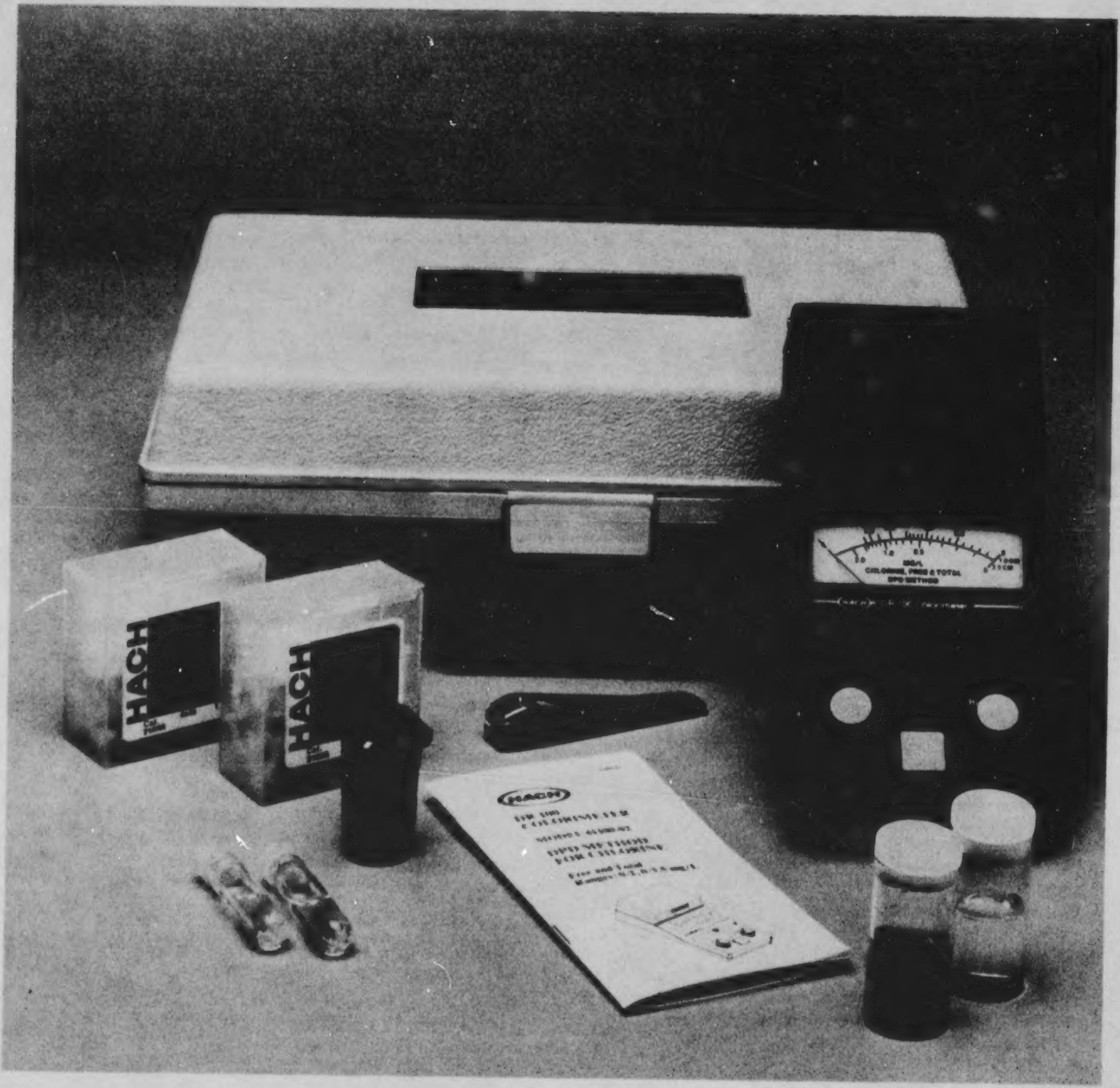

HACH
HACH
HACH
1.0
0.5
MG/L
CHLORINE, FREE & TOTAL
DPD METHOD

Fig. 7.34 Direct reading colorimeter for free chlorine residuals

(Permission of the Hach Company)

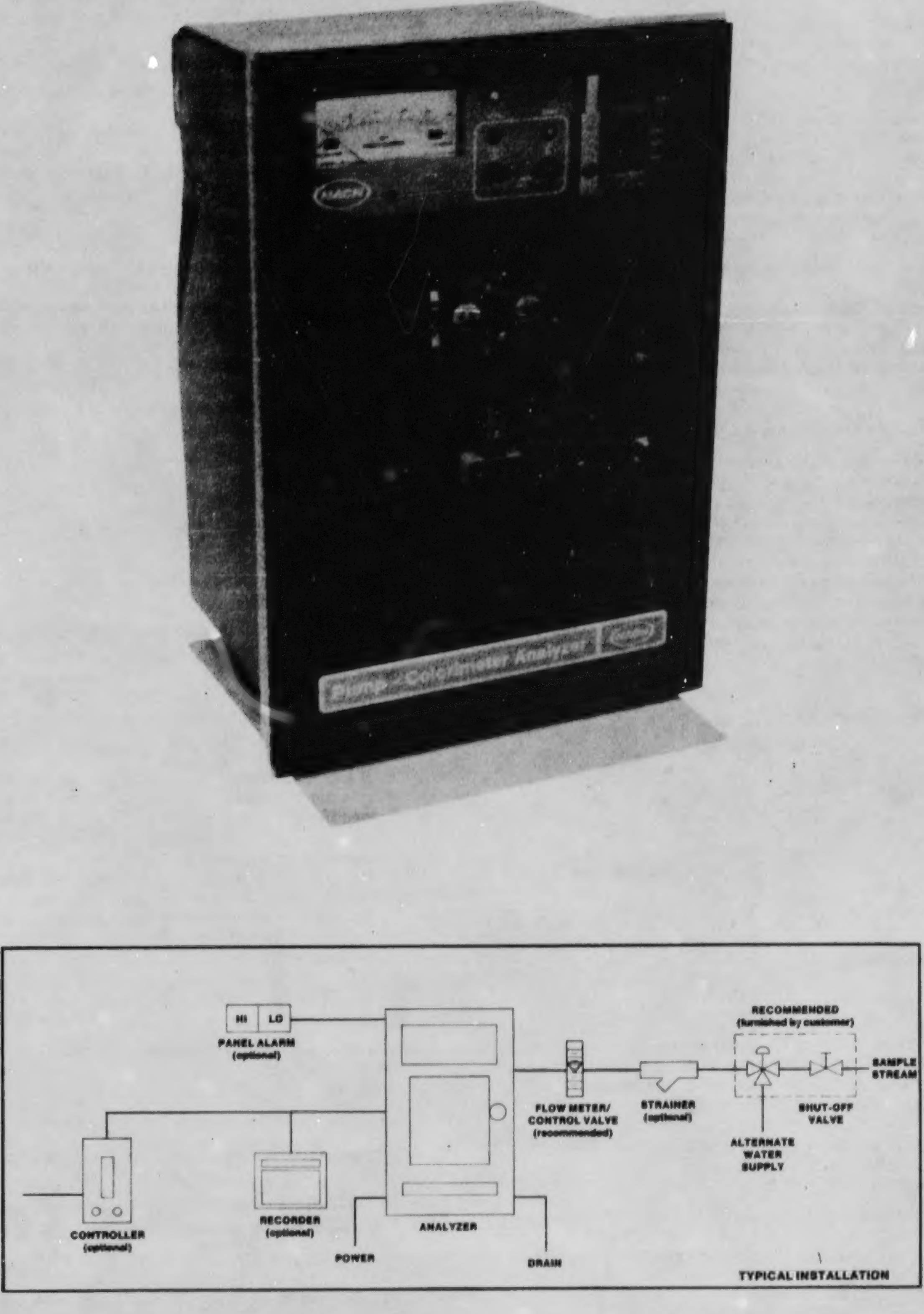

HACH
Pump Colorimeter Analyzer
HI
LO
PANEL ALARM
(optional)
RECOMMENDED
(furnished by customer)
SAMPLE STREAM
FLOW METER/
CONTROL VALVE
(recommended)
STRAINER
(optional)
SHUT-OFF VALVE
ALTERNATE WATER SUPPLY
CONTROLLER
(optional)
RECORDER
(optional)
ANALYZER
POWER
DRAIN
TYPICAL INSTALLATION

Fig. 7.35 Continuous on-line free chlorine residual analyzer

(Permission of the Hach Company)

7.81 Why Chlorine Must Be Handled With Care

You must always remember that chlorine is a hazardous chemical and must be handled with respect. Concentrations of chlorine gas in excess of 1000 ppm may be fatal after a few breaths.

Because the characteristic sharp odor of chlorine is noticeable even when the amount in the air is small, it is usually possible to get out of the gas area before serious harm is suffered. This feature makes chlorine less hazardous than gases such as carbon monoxide, which is odorless, and hydrogen sulfide, which impairs your sense of smell in a short time.

Inhaling chlorine causes general restlessness, panic, severe irritation of the throat, sneezing, and production of much saliva. These symptoms are followed by coughing, retching and vomiting, and difficulty in breathing. Chlorine is particularly irritating to persons suffering from asthma and certain types of chronic bronchitis. Liquid chlorine causes severe irritation and blistering on contact with the skin.

7.82 Protect Yourself From Chlorine

Every person working with chlorine should know the proper ways to handle it, should be trained in the use of self contained breathing apparatus, and should know what to do in case of emergencies. The clothing of persons exposed to chlorine will be saturated with chlorine which will irritate the skin if exposed to moisture or sweat. These people should not enter confined spaces before their clothing is purged of chlorine (stand out in the open air for awhile). This is particularly applicable to police and fire department personnel who leave the scene of a chlorine leak and ride back to their stations in closed vehicles.

WARNING

CANISTER TYPE '**GAS MASKS**' ARE USUALLY **INADEQUATE** AND **INEFFECTIVE** IN SITUATIONS WHERE CHLORINE LEAKS OCCUR AND ARE THEREFORE NOT RECOMMENDED FOR USE UNDER ANY CIRCUMSTANCES. **SELF-CONTAINED AIR OR OXYGEN SUPPLY TYPE BREATHING APPARATUS ARE RECOMMENDED.**

Self-contained air supply and demand-breathing equipment must fit properly and be used properly. Pressure demand and rebreather kits may be safer. Pressure demand units use more air from the air bottle which reduces the time a person may work on a leak.

Before entering an area with a chlorine leak, wear protective clothing. Gloves and a rubber suit will prevent chlorine from contacting the sweat on your body and forming hydrochloric acid. Rubber suits are very cumbersome, but should be worn when the weather it hot and humid and the chlorine concentration is high. Otherwise, use your own judgment regarding whether or not to wear protective clothing.

The best protection that one can have when dealing with chlorine is to respect it. Each individual should practice rules of safe handling and good PREVENTIVE MAINTENANCE.

PREVENTION IS THE BEST EMERGENCY TOOL YOU HAVE.

PLAN AHEAD.

1. Have your fire department tour the area so that they know where the facilities are located. Give them a clearly marked map indicating the location of the chlorine storage area, chlorinators, and gas masks.
2. Have emergency drills using chlorine gas masks and chlorine repair kits.
3. Have a supply of ammonia available to detect chlorine leaks.
4. Write emergency procedures:

   Prepare a CHLORINE EMERGENCY LIST of names or companies and phone numbers of persons to call during an emergency. This list should include:

   a. Fire department,
   b. Chlorine emergency personnel, and
   c. Chlorine supplier.
5. Follow established procedures during all emergencies.
   a. Never work alone during chlorine emergencies.
   b. Obtain help immediately and quickly repair the problem. PROBLEMS DO NOT GET BETTER.
   c. Only authorized and properly trained persons with adequate equipment should be allowed in the danger area to correct the problem.
   d. If you are caught in a chlorine atmosphere without a gas mask, shallow breathing is safer than breathing deeply. Recovery depends upon the duration and amount of chlorine inhaled, so it is important to keep that amount as small as possible.
   e. If you discover a chlorine leak, leave the area immediately unless it is a very minor leak. Small leaks can be found by using a rag soaked with ammonia. A white gas will form near the leak so it can be located and corrected.
   f. Notify your police department that you need help if it becomes necessary to stop traffic on roads and to evacuate persons in the vicinity of the chlorine leak.
6. Develop emergency evacuation procedures for use during a serious chlorine leak. Coordinate these procedures with your police department and other officials.
7. Post emergency procedures in all operating areas.
8. Inspect equipment and routinely make any necessary repairs.
9. At least twice weekly, inspect area where chlorine is stored and where chlorinators are located. Remove all obstructions from the area.
10. Schedule routine maintenance on ALL chlorine equipment at least once every six months or more frequently.
11. Have health appraisal for employees on chlorine emergency duty. No one with heart and respiratory problems should be allowed on emergency teams.

REMEMBER:

Small amounts of chlorine cause large problems. Leaks never get better.

7.83 First Aid Measures

MILD CASES

Whenever you have a mild case of chlorine exposure (which does happen from time to time around chlorination equipment), you should first leave the contaminated area. Move slowly, breathe lightly without exertion, remain calm, keep warm and resist coughing. Notify other operators and have them repair the leak immediately.

If clothing has been contaminated, remove as soon as possible. Otherwise the clothing will continue to give off chlorine gas which will irritate the body even after leaving the contaminated area. Immediately wash off area affected by chlorine. Shower and put on clean clothes.

If victim has slight throat irritation, immediate relief can be accomplished by drinking milk. Drinking spirits of peppermint also will help reduce throat irritation. See a physician.

EXTREME CASES

1. Follow established emergency procedures.
2. Always use proper safety equipment. Do not enter area without a self-contained breathing apparatus.
3. Remove patient from affected area immediately.
4. First aid:
   a. Remove contaminated clothes to prevent clothing giving off chlorine gas which will irritate the body.
   b. Keep patient warm and cover with blankets if necessary.
   c. Place patient in a comfortable position on back.
   d. EYES!
   If even a small amount of chlorine gets into the eyes, they should be flushed with water. The flushing should continue so that all traces of chlorine are flushed from the eyes.
5. See a physician.

7.84 Hypochlorite Safety

Hypochlorite does not present the hazards that gaseous chlorine does and therefore is safer to handle. When spills occur, wash with large volumes of water. The solution is messy to handle. Hypochlorite causes damage to your eyes and skin upon contact. Immediately wash affected areas thoroughly with water. Consult a physician if the area appears burned. Hypochlorite solutions are very corrosive. There are no fire hazards associated with the handling of hypochlorite.

7.85 Chlorine Dioxide Safety

Chlorine dioxide is generated in much the same manner as chlorine and should be handled with the same care. Of special concern is the use of sodium chlorite to generate chlorine dioxide. Sodium chlorite is very combustible around organic compounds. Whenever spills occur, sodium chlorite must be neutralized with anhydrous sodium sulfite. Combustible materials (including gloves) should not be worn when handling sodium chlorite. If sodium chlorite comes in contact with clothing, the clothes should be removed immediately and soaked in water to remove all traces of sodium chlorite or the clothes should be burned immediately.

7.86 Operator Safety Training

Training is a concern to everyone, especially when your safety and perhaps your life is concerned. Every utility agency should have an operator chlorine safety training program which introduces new operators to the program and updates previously trained operators. As soon as a training session ends, obsolescence begins. People will forget what they have learned if they don't use and practice their knowledge and skills. Operator turnover can dilute a well-trained staff. New equipment and also new techniques and procedures can dilute the readiness of trained operators. An on-going training program can consist of a monthly luncheon seminar, a monthly safety bulletin that is to be read by every operator, and outside speakers can be brought in to reinforce and refresh specific elements of a safety training program.

The American Water Works Association (AWWA) is an excellent source of training materials for safety programs. Films are available from AWWA for rental fees of around $15.00. Typical films include "A Demonstration of the A, B and C Emergency Kits." This film illustrates the application of the Chlorine Institute's A, B and C emergency repair devices. "Safe Handling of Chlorine" is a film about procedures for handling chlorine cylinders, ton containers, tank cars and barges. Also discussed are appropriate materials for construction, pumping chlorine, checking storage tanks, operating vaporizers, repacking valves, and training operators how to safely handle chlorine. To obtain these and other films, write or call AWWA, Library, 6666 West Quincy Avenue, Denver, Colorado 80235; phone 303-794-7711.

7.87 CHEMTREC (800-424-9300)

Safely handling chemicals used in daily water treatment is an operator's responsibility. However, if the situation ever gets out of hand, there are emergency teams that will respond with help anywhere there is an emergency. If an emergency does develop in your plant and you need assistance, call CHEMTREC (Chemical Transportation Emergency Center) for assistance. CHEMTREC will provide immediate advice for those at the scene of an emergency and then quickly alert experts whose products are involved for more detailed assistance and appropriate follow-up.

CHEMTREC'S EMERGENCY TOLL-FREE PHONE NUMBER IS 800-424-9300.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 328.

7.8A What are the hazards of chlorine gas?

7.8B What type of breathing apparatus is used when repairing chlorine leaks?

7.8C What first aid measures should be taken if a person comes in contact with chlorine?

7.9 OPERATION OF OTHER DISINFECTION PROCESSES

7.90 Ultraviolet (UV) Systems

7.900 Process Description

The operation of ultraviolet water disinfection systems (Figures 7.36 and 7.37) requires very little in the way of attention by operators. The system needs nothing more than electrical hookups. Water is disinfected as it passes by UV lamps. Care must be taken not to exceed maximum design turbidity levels and flows when using this type of equipment.

Since ultraviolet rays leave no chemical residual like chlorine does, bacteriological tests must be made frequently to insure that adequate disinfection is being achieved by the ultraviolet system. In addition, the lack of residual disinfectant means that no protection is provided the treated water against recontamination after it has left the disinfection facility.

7.901 Ultraviolet System Hardware

1. Teflon Tube (Figures 7.36 and 7.37)

The water that is to be disinfected flows inside teflon tubes which are surrounded by germicidal UV lamps. The UV light penetrates the teflon tube and is absorbed by the fluid. The advantage to this system is water never comes in contact with the lamps. Wiping devices are not needed so the hardware is relatively simple and very reliable.

The only disadvantage that the system has is no large installations have been constructed; therefore, it has no track record.

2. Thin Film

This system utilizes a chamber with lots of lamps. The lamps are only one-quarter inch (6 mm) apart. This system has been used in the wastewater industry for a 9 MGD (0.35 cu m/sec) secondary type plant and has been operating for several years.

3. Box System

This system is simply a box with UV lamps inside. This system requires a lamp cleaning device.

7.902 Problems and Solutions

1. Use of Technology — Lack of Track Record

EPA has used UV systems on demonstration projects. Otherwise there has not been extensive use of UV systems by the water industry.

2. Turbidity

Turbidity will hinder the disinfection properties of the UV system. To minimize this problem, the flow past the UV source has to be turbulent. The UV source is placed so that UV light is received by the water being disinfected from all angles.

3. Short-Circuiting

Some UV systems have been shown to short-circuit and allow some water to flow through the system and not be disinfected. One solution to this problem is to use conservative design. The use of turbulent flows causes good mixing and good exposure of the water to UV light.

4. Reactivation of Microorganisms

When the treated water is exposed to visible light, the microorganisms can be reactivated. Microorganisms that have not been killed have the ability of healing when exposed to sunlight. The solution to this problem is to design UV systems with a high efficiency for killing microorganisms.

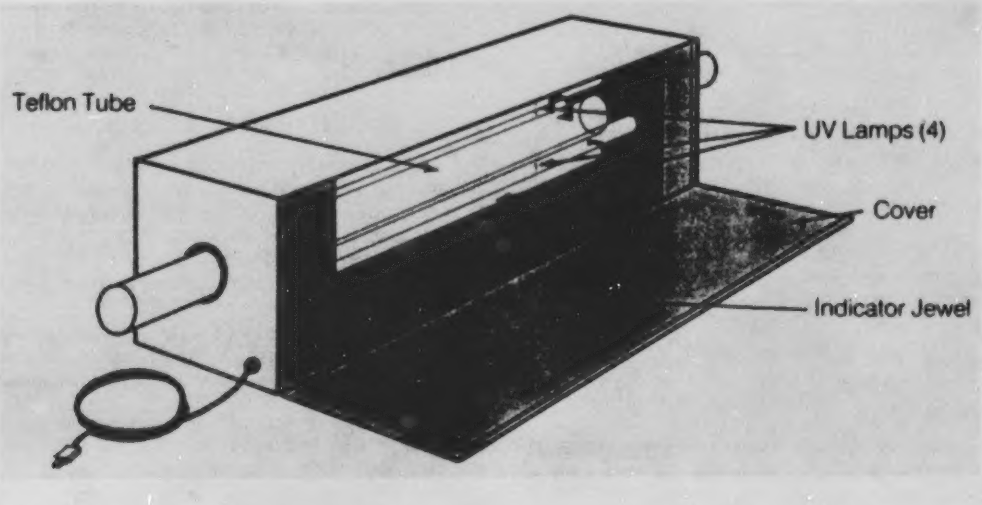


Fig. 7.36 Ultraviolet system
(Permission of Gaston Systems, Inc.)

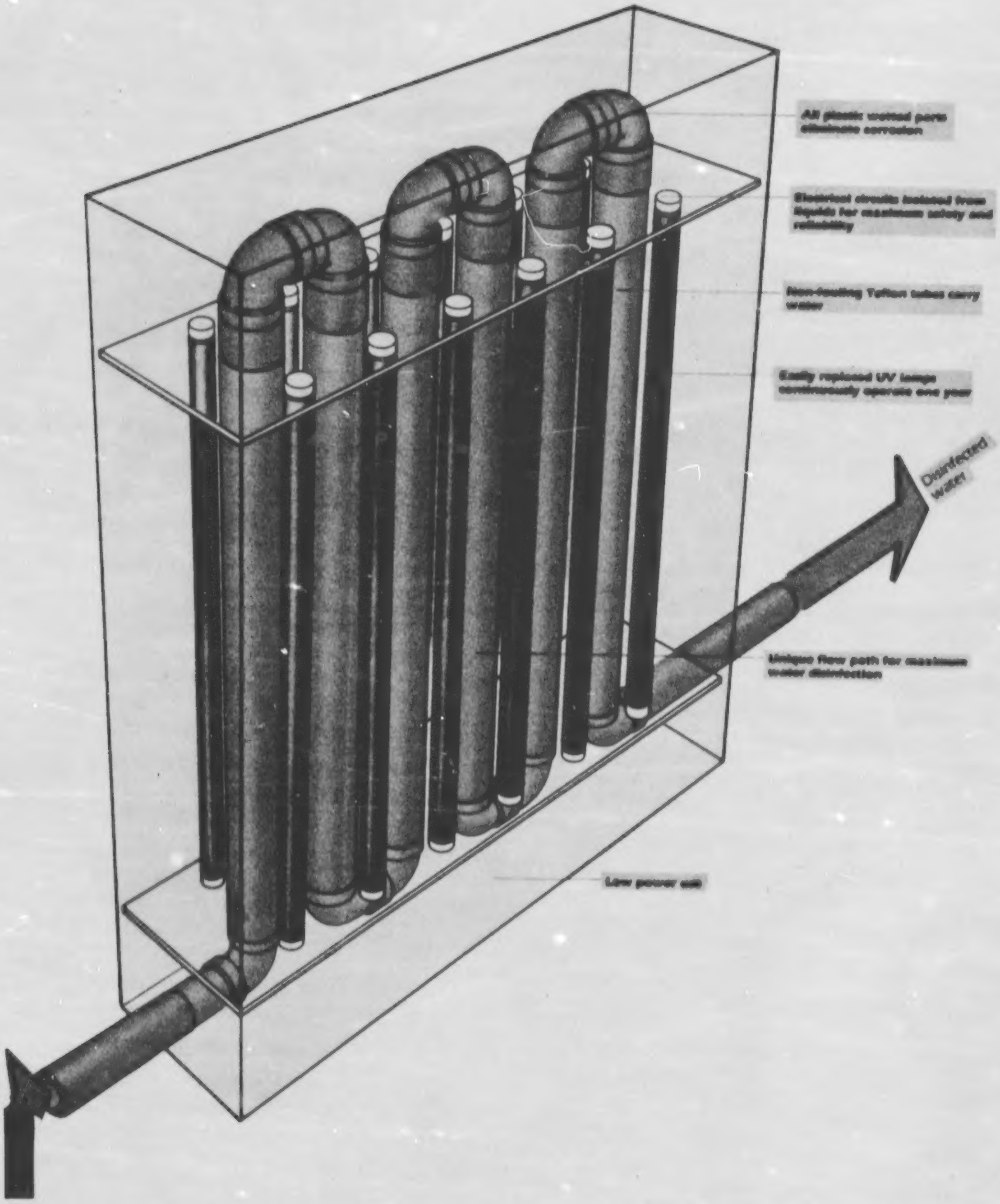

All plastic wetted parts eliminate corrosion
Electrical circuits isolated from liquids for maximum safety and reliability
Non-fouling Teflon tubes carry water
Easily replaced UV lamps continuously operate one year
Disinfected water
Unique flow path for maximum water disinfection
Low power use

Fig. 7.37 Ultraviolet disinfection system

(Permission of Ultraviolet Technology, Inc.)

5. Disinfection

Modern systems can be monitored with a UV intensity measuring device to indicate an effective kill of microorganisms.

7.91 Ozone

7.910 Equipment

Ozone is normally prepared on site because it is very unstable. Ozonation equipment (Figures 7.38 and 7.39) consist of four major parts:

1. Gas preparation unit,
2. Electrical power unit,
3. Ozone generator, and
4. Contactor.

Gages, controls, safety equipment and housing are also needed.

7.911 Gas Preparation

The gas preparation unit to produce dry air usually consists of a commercial air dryer with a dew point monitoring system. This is the most critical part of the system.

7.912 Electrical Supply Unit

This unit is normally a very special electrical control system. The most common electrical supply unit provides low frequency, variable voltage. For large installations, medium frequency, variable voltage is used to reduce power costs and because it allows for higher output of ozone.

7.913 Ozone Generator (Figures 7.39 and 7.40)

This unit consists of a pair of electrodes separated by a gas space and a layer of glass insulation. An oxygen-containing gas (air) is passed through the empty space as a high voltage alternating current is applied. An electrical discharge occurs across the gas space and ozone is formed when a portion of the oxygen is ionized and then becomes associated with non-ionized oxygen molecules.

Oxygen From Air + High Electrical Voltage → Ionized Oxygen + Heat

$O_2 \rightarrow 2(0)$

and

Ionized Oxygen + Non-Ionized Oxygen → Ozone

$2(0) \quad 2(O_2) \quad 2(O_3)$

7.914 Ozone Contactor

This unit is a mixing chamber for the ozone-rich material and the process water. The objective is to dissolve enough ozone in the water to achieve disinfection at the lowest possible cost. These units are available in many configurations.

1. Multi-Stage Porous Difuser
   a. Single application of an ozone-rich stream
   b. Application of ozone to second state
2. Eductor System
   a. Total flow through eductor
   b. Partial plant flow through the eductor
3. Turbine
   a. Positive pressure
   b. Negative pressure
4. Packed bed
   a. Concurrent ozone-rich flow
   b. Countercurrent ozone-rich flow
5. Two-level diffuser
   a. Lower chamber off gases applied to upper chamber
   b. Application of ozone-rich gas to lower chamber

For disinfection purposes, the diffuser-type ozone contact (#5 above) is the most commonly used design. The off gases must be treated prior to release to the atmosphere. The most common method of treatment is the use of activated carbon and dilution.

7.915 Ozone Residuals

Residual ozone is measured by the iodometric method. The procedure is as follows:

1. Collect 800 m*L* sample in 1 liter wash bottle.
2. Pass pure air or nitrogen through sample and then through an absorber containing 400 m*L* KI solution. Continue for 5 to 10 minutes at a rate of 1.0 liter/minute to purge all ozone from sample.
3. Transfer KI solution.
4. Add 20 m*L* 1 *N* H_2SO_4 to reduce pH to 2.
5. Titrate with .005 *N* sodium thiosulfate solution.
6. Add several drops of starch.
7. End point is reached when starch turns purple.
8. Repeat test using blank or distilled water.
9. Calculation

$$\text{mg } O_3/L = \frac{(A \pm B) \times N \times 24{,}000}{mL \text{ of sample}}$$

where:

A = m*L* of titrant for sample,

B = m*L* of titrant for blank (positive if turned blue and negative if had to back titrate blank), and

N = normality of sodium thiosulfate

Continuous on-line ozone residual analyzers are available similar to the continuous on-line chlorine residual analyzers (Figure 7.35).

7.916 Safety

Ozone is a toxic gas and also is a hazard to plants and animals. When ozone breaks down in the atmosphere as a result of photochemical reactions (reactions taking place in the presence of sunlight), the resulting atmospheric pollutants can be very harmful. However, ozone is less of a hazard than gaseous chlorine. This is due to the fact that chlorine is normally manufactured and delivered to the plant

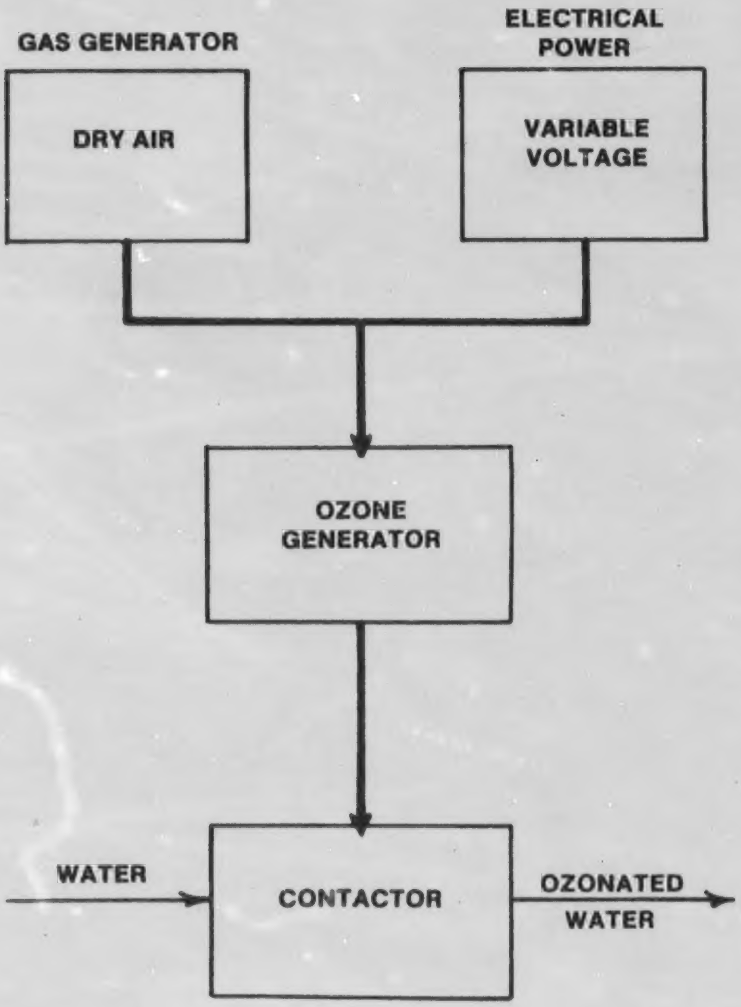
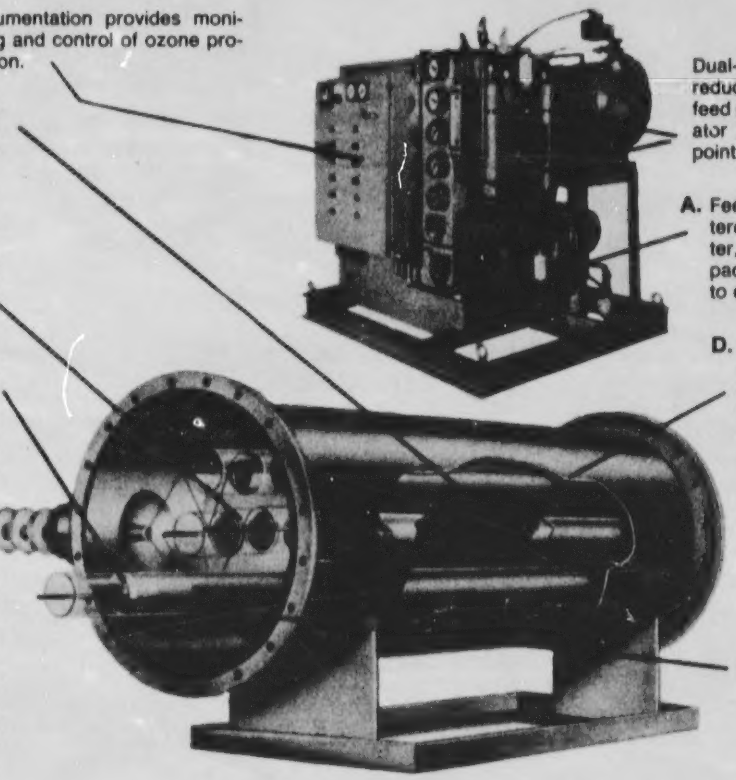

GAS GENERATOR
DRY AIR
ELECTRICAL POWER
VARIABLE VOLTAGE
OZONE GENERATOR
WATER
CONTACTOR
OZONATED WATER

Fig. 7.38 Ozonation equipment

The basic system for ozone production is presented in the diagram below. The ozone-producing unit, or ozonator, is fed an oxygen-containing gas that has first been cleaned and dried (A). As oxygen molecules (O_2) travel through the discharge gap (B) and are subjected to corona discharge, some are separated into free oxygen atoms (O) which combine with intact molecules to form ozone (O_3). Power (C) is required to generate the corona discharge, and the heat given off during ozonation is dissipated by some form of cooling process (D).



Instrumentation provides monitoring and control of ozone production.

Ozonator dielectric assemblies convert oxygen to ozone by means of a high-voltage corona discharge.

B. The ozonator dielectric assembly consists of two electrode surfaces separated by a glass dielectric and an open gap. Feed gas moves through the gap during ozone production.

Deflectors at the ends of the ozonator tubes prevent discharge arcs, allowing higher-voltage operation for more efficient ozone production, and ensuring longer life for the ozonator dielectric.

C. Electrical power is used to create the corona discharge. Ozone production is controlled by varying the voltage supplied to the ozonator tubes. Feed gas, rich in ozone, leaves the ozonator tubes and is carried to the contactor, where it is mixed with the materal to be treated.

Dual-tower regenerative driers reduce moisture content of the feed gas. Gas entering the ozonator has been dried to a dew point of about −51°C (−60°F).

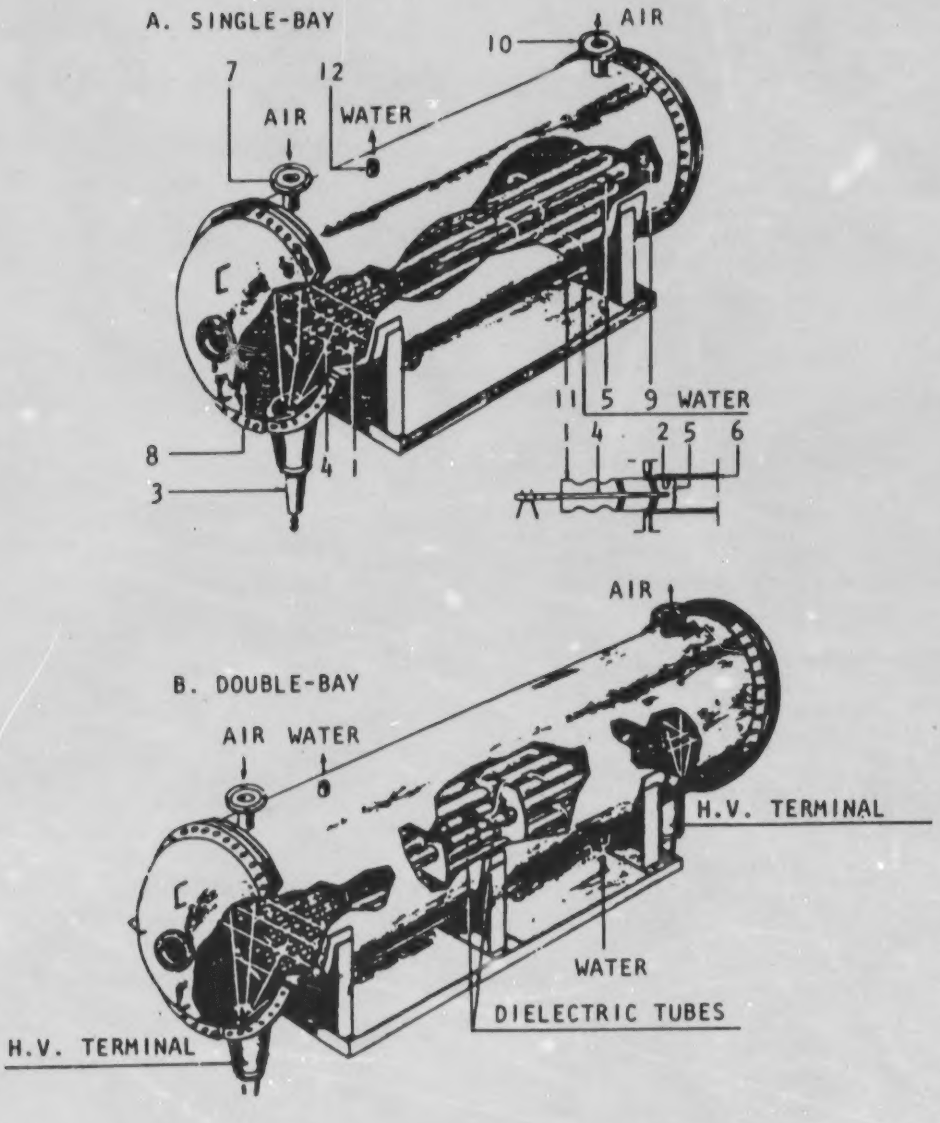
A. Feed gas (air or oxygen) is filtered to remove particulate matter, run through the compressor package, then filtered again prior to entering the driers.

D. The corona discharge within the ozonator tubes creates a considerable amount of heat. Ozonators are cooled by a continuous flow of water in the outer shell of the tube-and-shell design.

Special high-voltage fuses protect each dielectric assembly.

Fig. 7.39 Ozone generation

(Permission of Walsbach Ozone Systems Corporation)


A. SINGLE-BAY
AIR
10
7
12
AIR
WATER
11
5
9
WATER
1
4
2
5
6
8
4
1
3
AIR
B. DOUBLE-BAY
AIR
WATER
H.V. TERMINAL
WATER
DIELECTRIC TUBES
H.V. TERMINAL

1. DIELECTRIC TUBE
2. METALLIC COATING
3. H.V. TERMINAL
4. CONTACT
5. CENTERING PIECE
6. IONIZATION GAP
7. AIR INLET
8. FRONT CHAMBER
9. REAR CHAMBER
10. AIR OUTLET
11. WATER INLET
12. WATER OUTLET

Fig. 7.40 Typical details of horizontal tube-type ozone generator

site. Ozone is produced on the site, it is used in low concentrations, and it is not stored under pressure. Problem leaks can be stopped by turning the unit off. Ozone produces an irritation of the nasal passages in low concentrations.

Ozone production equipment has various fail-safe protection devices which will automatically shut off the equipment when a potential hazard develops.

7.917 Maintenance

Electrical equipment and pressure vessels should be inspected monthly by trained operators. A yearly preventive maintenance program should be conducted by factory representatives or by an operator trained by the manufacturer.

Lubrication of the moving parts should be done according to the manufacturer's recommended schedule.

7.918 Applications of Ozone (Figure 7.41)

In addition to using ozone for bacterial disinfection and viral inactivation, ozone may also be used for several other purposes in treating drinking waters. Ozone may be used prior to coagulation for treating iron and manganese, helping flocculation and removing algae. When ozone is applied before filtration, it may be used for oxidizing organics, removing color or treating tastes and odors.

7.919 Advantages and Limitations of Ozone

ADVANTAGES

1. Better virucide than chlorine.
2. Removes color, odor, and tastes (phenols).
3. Increases dissolved oxygen.
4. Oxidizes iron, manganese, sulfide, and organics.

LIMITATIONS

1. Cost.
2. Maintenance.
3. Safety.
4. Disinfection - unpredictable.
5. Not able to meet MPNs of less than 2.2 coliforms per 100 m*L* consistently.
6. Operational constraints.
7. No track record.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 329.

7.9A What precautions must be exercised by the operators of ultraviolet disinfection systems.

7.9B Why is ozone normally prepared on site?

7.9C Why is ozone less of a hazard than gaseous chlorine?

7.10 Typical Chlorination Arithmetic Problems

7.100 Chlorinators

EXAMPLE 5

At 8:00 am on Monday morning a chlorine cylinder weighs 83 pounds. At 8:00 am Tuesady morning the same cylinder weighs 69 pounds. What is the chlorinator feed rate in pounds per 24 hours?

KNOWN		UNKNOWN
Monday weight, lbs	=83 lbs	Chlorinator Feed Rate, lbs/24 hours
Tuesday weight, lbs	=69 lbs	
Time period, hrs	=24 hours	

Calculate the chlorinator feed rate in pounds per 24 hours.

$$\text{Chlorinator Feed Rate, lbs/24 hrs} = \frac{\text{Initial Weight, lbs} - \text{Final Weight, lbs}}{\text{Time Period, hrs}}$$

$$= \frac{83 \text{ lbs} - 69 \text{ lbs}}{24 \text{ hours}}$$

$$= 14 \text{ lbs/24 hours}$$

$$\text{or} \quad = 14 \text{ lbs/day}$$

NOTE: The chlorinator setting should read 14 pounds per 24 hours.

EXAMPLE 6

Estimate the chlorine dose in mg/*L* for the chlorinator in EXAMPLE 5. The flow totalizer read 12,982,083 gallons at 8:00 am on Monday morning and 13,528,924 at 8:00 am on Tuesday morning. Fourteen pounds of chlorine were fed during the 24-hour period.

KNOWN		UNKNOWN
Monday Flow, gal	=12,982,083 gal	Chlorine Dose, mg/*L*
Tuesday Flow, gal	=13,528,924 gal	
Chlorine Feed, lbs/day	=14 lbs/day	
Time Period, day	=1 day	

Calculate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg}/L = \frac{(\text{Chlorine Feed, lbs/day})(\text{Time, day})}{(\text{Tues Flow, M Gal} - \text{Mon Flow, M Gal})(8.34 \text{ lbs/gal})}$$

$$= \frac{(14 \text{ lbs/day})(1 \text{ day})}{(13.53 \text{ M Gal} - 12.98 \text{ M Gal})(8.34 \text{ lbs/gal})}$$

$$= \frac{14 \text{ lbs chlorine}}{(0.55 \text{ M Gal})(8.34 \text{ lbs/gal})}$$

$$= \frac{14 \text{ lbs chlorine}}{4.59 \text{ M lbs water}}$$

$$= 3.05 \text{ lbs chlorine/M lbs water}$$

$$= 3.1 \text{ mg}/L$$

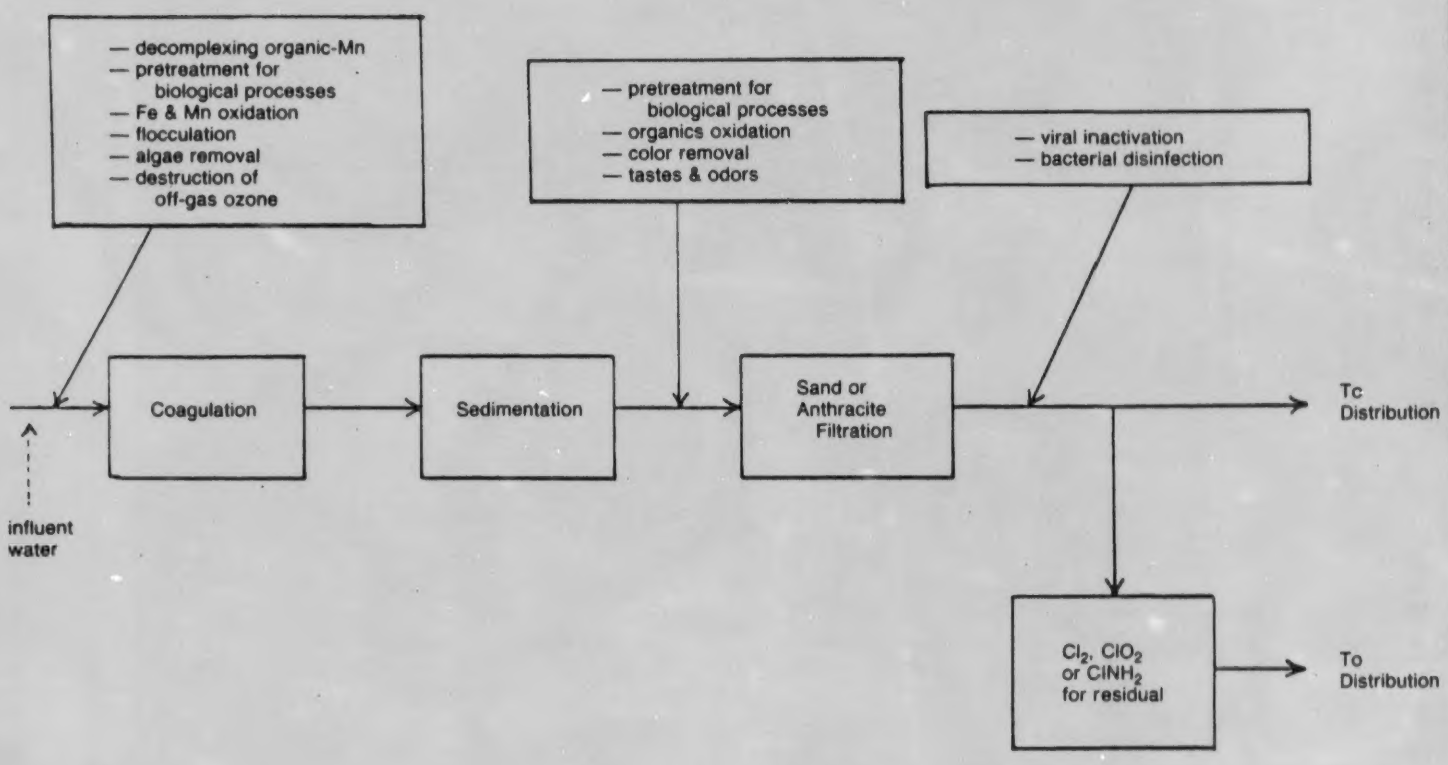

— decomplexing organic-Mn
— pretreatment for biological processes
— Fe & Mn oxidation
— flocculation
— algae removal
— destruction of off-gas ozone
— pretreatment for biological processes
— organics oxidation
— color removal
— tastes & odors
— viral inactivation
— bacterial disinfection
influent water
Coagulation
Sedimentation
Sand or Anthracite Filtration
Tc Distribution
Cl_2, ClO_2 or $ClNH_2$ for residual
To Distribution

Fig. 7.41 Typical points of application of ozone in drinking water processes

EXAMPLE 7

A centrifugal pump delivers approximately 200 GPM (gallons per minute) against typical operating heads. If the desired chlorine dosage is 3 mg/*L*, what should be the setting on the rotameter for the chlorinator (lbs chlorine per 24 hours)?

KNOWN		UNKNOWN
Pump Flow, GPM	=200 GPM	Rotameter Setting, lbs chlorine/24 hours
Chlorine Dose, mg/*L*	=3 mg/*L*	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = \frac{(200\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{(1{,}000{,}000)}$$

$$= 0.288\text{ MGD}$$

2. Calculate the rotameter setting in pounds of chlorine per 24 hours.

$$\text{Rotameter Setting, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

$$= (0.288\text{ M Gal/day})(3\text{ lbs/M lbs})(8.34\text{ lbs/gal})$$

$$= 7.2\text{ lbs/day}$$

$$= 7.2\text{ lbs/24 hours}$$

EXAMPLE 8

Using the results from EXAMPLE 7 (a chlorinator setting of 7.2 lbs/day), how many pounds of chlorine would be used during one week if the pump hour meter showed 100 hours of pump operation? If the chlorine cylinder contained 78 pounds of chlorine at the start of the week, how many pounds of chlorine should be remaining at the end of the week?

UNKNOWN		UNKNOWN
Chlorinator Setting, lbs/day	=7.2 lbs/day	1. Chlorine Used, lbs/week
Time, hrs/week	=100 hrs/week	2. Chlorine Remaining, lbs
Chlorine Cylinder, lbs	=78 lbs	

1. Calculate the chlorine used in pounds per week.

$$\text{Chlorine Used, lbs/week} = (\text{Chlorinator Setting, lbs/day})(\text{Time, hrs/week})$$

$$= (7.2\text{ lbs/day})\left(\frac{100\text{ hrs/wk}}{24\text{ hrs/day}}\right)$$

$$= 30\text{ lbs chlorine/week}$$

2. Determine the amount of chlorine that should be in the cylinder at the end of the week.

$$\text{Chlorine Remaining, lbs} = \text{Chlorine at Starts, lbs} - \text{Chlorine Used, lbs}$$

$$= 78\text{ lbs} - 30\text{ lbs}$$

$$= 48\text{ lbs chlorine remaining at end of week}$$

EXAMPLE 9

Given the pumping and chlorination system in EXAMPLES 7 and 8. If 30 pounds of chlorine are used during an average week, how many 150-pound chlorine cylinders will be used per month (assume 30 days per month).

KNOWN		UNKNOWN
Chlorine Use, lbs/week	=30 lbs/week	1. Amount of Chlorine Used per Month, lbs 2. Number of 150-lb Cylinders Used per Month

1. Calculate the amount of chlorine used in pounds of chlorine per month.

$$\text{Chlorine Used, lbs/mo} = (\text{Chlorine Use, lbs/week})(\text{Number Weeks/mo})$$

$$= (30\text{ lbs/week})\left[\frac{(1\text{ week})(30\text{ days})}{(7\text{ days})(1\text{ mo})}\right]$$

$$= 128\text{ lbs/mo}$$

2. Determine the number of 150-pound chlorine cylinders used per month.

$$\text{Cylinders Used, number/month} = \frac{\text{Chlorine Used, lbs/mo}}{\text{Chlorine Cylinders, lbs/cylinder}}$$

$$= \frac{128\text{ lbs/mo}}{150\text{ lbs/cylinder}}$$

$$= 0.86\text{ cylinders/month}$$

This installation requires less than one 150-pound chlorine cylinder per month.

7.101 Hypochlorinators

EXAMPLE 10

Water from a well is being treated by a hypochlorinator. If the hypochlorinator is set at a pumping rate of 50 gallons per day (GPD) and uses a three-percent available chlorine solution, what is the chlorine dose in mg/*L* if the pump delivers 350 GPM?

KNOWN		UNKNOWN
Hypochlorinator, GPD	=50 GPD	Chlorine Dose, mg/*L*
Hypochlorite, %	=3%	
Pump, GPM	=350 GPM	

1. Convert the pumping rate to MGD.

$$\text{Pumping Rate, MGD} = (350\text{ GM})\left[\frac{(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{(1{,}000{,}000)}\right]$$

$$= 0.50\text{ MGD}$$

2. Calculate the chlorine feed rate in pounds per day.

$$\text{Chlorine Feed, lbs/day} = \frac{(\text{Flow gal/day})(\text{Hypochlorite, \%})(8.34\text{ lbs/gal})}{100\%}$$

$$= \frac{(50\text{ gal/day})(3\%)(8.34\text{ lbs/gal})}{100\%}$$

$$= 12.5\text{ lbs/day}$$

3. Estimate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorine Feed, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{12.5\text{ lbs chlorine/day}}{(0.50\text{ M gal/day})(8.34\text{ lbs/gal})}$$

$$= 3\text{ lbs chlorine/M lbs water}$$

$$= 3\text{ mg}/L$$

EXAMPLE 11

Water pumped from a well is disinfected by a hypochlorinator. During a one-week time period the water meter indicated that 1,098,000 gallons of water were pumped. A 2.0 percent sodium hypochlorite solution is stored in a 2.5-foot diameter plastic tank. During this one-week time period, the level of hypochlorite in the tank dropped 18 inches (1.50 ft). What was the chlorine dose in mg/*L*?

KNOWN		UNKNOWN
Water Treated, M Gal	= 1.098 M Gal	Chlorine Dose, mg/*L*
Hypochlorite, %	= 2.0%	
Hypochlorite Tank D, ft	= 2.5 ft	
Hypochlorite Used, ft	= 1.5 ft	

1. Calculate the pounds of water disinfected.

$$\text{Water, lbs} = (\text{Water Treated, M Gal})(8.34\ \text{lbs/gal})$$

$$= (1.098\ \text{M Gal})(8.34\ \text{lbs/gal})$$

$$= 9.16\ \text{M lbs water}$$

2. Calculate volume of the hypochlorite solution used in gallons.

$$\text{Hypochlorite, gal} = (0.785)(\text{Diameter, ft})^2(\text{Drop, ft})(7.48\ \text{gal/cu ft})$$

$$= (0.785)2.5\ \text{ft})^2(1.5\ \text{ft})(7.48\ \text{gal/cu ft})$$

$$= 55.0\ \text{gallons}$$

3. Determine the pounds of chlorine used to treat the water.

$$\text{Chlorine, lbs} = (\text{Hypochlorite, gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)(8.34\ \text{lbs/gal})$$

$$= (55.0\ \text{gal})\left(\frac{2.0\%}{100\%}\right)(8.34\ \text{lbs/gal})$$

$$= 9.17\ \text{lbs chlorine}$$

4. Estimate the chlorine dose in mg/*L*.

$$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorine Used, lbs}}{\text{Water Treated, Million lbs}}$$

$$= \frac{9.17\ \text{lbs Chlorine}}{9.16\ \text{M lbs Water}}$$

$$= \frac{1.0\ \text{lbs Chlorine}}{1\ \text{M lbs Water}}$$

$$= 1.0\ \text{mg/}L$$

EXAMPLE 12

Estimate the required concentration of a hypochlorite solution (%), if a pump delivers 600 GPM from a well. The hypochlorinator can deliver a maximum of 120 GPD and the desired chlorine dose is 1.8 mg/*L*.

KNOWN		UNKNOWN
Pump Flow, GPM	= 600 GPM	Hypochlorite Strength, %
Hypo Cl Flow, GPD	= 120 GPD	
Chlorine Dose, mg/*L*	= 1.8 mg/*L*	

1. Calculate the flow of water treated in million gallons per day.

$$\text{Water Treated, M gal/day} = (600\ \text{GPM})\left[\frac{(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{(1{,}000{,}000)}\right]$$

$$= 0.86\ \text{MGD}$$

2. Determine the pounds of chlorine required per day.

$$\text{Chlorine Required, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\ \text{lbs/gal})$$

$$= (0.86\ \text{MGD})(1.8\ \text{mg/}L)(8.34\ \text{lbs/gal})$$

$$= 12.9\ \text{lbs chlorine/day}$$

3. Calculate the hypochlorite solution strength as a percent.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, GPD})(8.34\ \text{lbs/gal})}$$

$$= \frac{(12.9\ \text{lbs/day})(100\%)}{(120\ \text{GPD})(8.34\ \text{lbs/gal})}$$

$$= 1.3\%$$

EXAMPLE 13

A hypochlorite solution for a hypochlorinator is being prepared in a 55-gallon drum. If 10 gallons of 5 percent hypochlorite is added to the drum, how much water should be added to the drum to produce a 1.3 percent hypochlorite solution?

KNOWN		UNKNOWN
Drum Capacity, gal	= 55 gal	Water Added, gal
Hypochlorite, gal	= 10 gal	
Hypochlorite, %	= 5%	
Desired Hypo, %	= 1.3%	

Calculate the volume of water to be added in gallons.

$$\text{Desired Hypo, \%} = \frac{(\text{Hypo, gal})(\text{Hypo, \%})}{\text{Hypo, gal} + \text{Water Added, gal}}$$

Rearrange the terms in the equation.

$$(\text{Desired Hypo, \%})(\text{Hypo, gal} + \text{Water Added, gal}) = (\text{Hypo, gal})(\text{Hypo, \%})$$

OR

$$(\text{Desired Hypo, \%})(\text{Hypo, gal}) + (\text{Desired Hypo, \%})(\text{Water Added, gal}) = (\text{Hypo, gal})(\text{Hypo, \%})$$

OR

$$(\text{Desired Hypo, \%})(\text{Water Added, gal}) = (\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Desired Hypo, \%})(\text{Hypo, gal})$$

OR

$$\text{Water Added, gal} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(10\ \text{gal})(5\%) - (10\ \text{gal})(1.3\%)}{1.3\%}$$

$$= \frac{50 - 13}{1.3}$$

$$= 28.5\ \text{gallons of water}$$

Add 28.5 gallons of water to the 10 gallons of 5 percent hypochlorite in the drum.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 329.

7.10A Estimate the chlorine demand of a water that is dosed at 2.0 mg/*L*. The chlorine residual is 0.2 mg/*L* after a 30-minute contact period.

7.10B What should be the setting on a chlorinator (lbs chlorine per 24 hours) if a pump usually delivers 600 GPM and the desired chlorine dosage is 4.0 mg/*L*?

7.10C Water from a well is being disinfected by a hypochlorinator. If the hypochlorinator is set at a pumping rate of 60 gallons per day (GPD) and uses a 2 percent available chlorine solution, what is the chlorine dose rate in mg/*L*? The pump delivers 400 GPM.

7.11 Arithmetic Assignment

Turn to the Appendix at the back of this manual and read all of Section A.7, "Velocity and Flow Rate."

In Section A.13, "Typical Water Treatment Plant Problems," read and work the problems in Section A.136, "Disinfection."

7.12 Additional Reading

1. *NEW YORK MANUAL*, Chapter 10, "Chlorination."
2. *TEXAS MANUAL*, Chapter 10, "Disinfection of Water."
3. *CHLORINE MANUAL*, The Chlorine Institute, Inc., 342 Madison Avenue, New York, N.Y. 10173. Price $5.00.
4. *CHLORINE MANUAL*, Chlor-Alkali Business Unit, Chemical Division, PPG Industries Inc., One Gateway Center, Pittsburgh, Pennsylvania 15222.
5. *CHLORINE SAFE HANDLING*, Chlor-Alkali Business Unit, Chemical Division, PPG Industries Inc., One Gateway Center, Pittsburgh, Pennsylvania 15222.
6. *BASIC GAS CHLORINATION WORKSHOP MANUAL*. Obtain from Training and Certification Section, Ministry of the Environment, 135 St. Clair Avenue West, Toronto 7, Ontario, M4V 1P5 CANADA.

End of Lesson 3 of 3 Lessons on DISINFECTION

DISCUSSION AND REVIEW QUESTIONS

Chapter 7. DISINFECTION

(Lesson 3 of 3 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 330. The problem numbering continues from Lesson 2.

12. Why is the room temperature important for proper chlorinator operation?
13. How should chlorinator rooms be ventilated?
14. Why must chlorination be continuous?
15. What are the advantages and limitations of the use of chlorine dioxide for disinfection?
16. List the items that should be included in all chlorine safety programs.
17. What precautions must be exercised by the operators of ultraviolet disinfection systems?
18. What are the possible uses of ozone for treating drinking water?

SUGGESTED ANSWERS

Chapter 7. DISINFECTION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 258.

7.0A Pathogenic organisms are disease-producing organisms.

7.0B Disinfection is the selective destruction of pathogenic organisms.

7.0C The US. Environmental Protection Agency establishes drinking water standards.

7.0D MCL stands for **M**aximum **C**ontaminant **L**evel.

Answers to questions on page 260.

7.1A Relatively cold water requires longer disinfection time or greater quantities of disinfectants.

7.1B Most disinfectants are more effective in water with a pH around 7.0 than in water above a pH of 8.0.

7.1C The greater the number and type of microorganisms present, the greater may be the adverse influence on the effectiveness of the disinfectant.

Answers to questions on page 261.

7.2A Physical agents that have been used for disinfection other than chlorine include (1) ultraviolet rays, (2) heat and (3) ultra sonic waves.

7.2B Chemical agents that have been used for disinfection other than chlorine include (1) iodine, (2) bromine, (3) bases (sodium hydroxide and lime), and (4) ozone.

7.2C A major limitation to the use of ozone is the inability of ozone to provide a residual in the distribution system.

Answers to questions on page 262.

7.2D Hydrogen sulfide and ammonia are two inorganic reducing chemicals that react rapidly with chlorine.

7.2E Chlorine Demand, mg/*L* = Chlorine Dose, mg/*L*, − Chlorine Residual, mg/*L*

7.2F Chlorine Dose, mg/*L* = Chlorine Demand, mg/*L* + Chlorine Residual, mg/*L*

Answers to questions on page 264.

7.2G The higher the pH level, the greater the percent of OCl^-.

7.2H Chlorine gas tends to lower the pH while hypochlorite tends to increase the pH.

Answers to questions on page 267.

7.2I Chlorine reacts with organic matter to form chlororganic compounds, including trihalomethanes.

7.2J Breakpoint chlorination is the addition of chlorine to water until the chlorine demand has been satisfied and further additions of chlorine result in a free available residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

Answers to questions on page 269.

7.3A The two most common points (locations) of chlorination in a water treatment plant are:

1. Prechlorination ahead of any other treatment processes, and
2. Postchlorination after the water has been treated and before it enters the distribution system.

7.3B The benefits of prechlorination include (1) control of algae and slime growths, (2) control of mud ball formation, (3) improved coagulation, (4) reduction of tastes and odors, (5) increased chlorine contact time, and (6) safety factor in disinfection of heavily contaminated water.

7.3C Waters should not be prechlorinated when the raw waters contain organic compounds. The addition of chlorine will result in the formation of trihalomethanes and tastes and odors (if phenolic compounds are present).

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 274.

7.4A Typical hypochlorinator systems consist of a chemical solution tank for the hypochlorite, diaphragm-type pump, power supply, water pump, pressure switch and water storage tank.

7.4B The two common methods of feeding hypochlorite to the water being disinfected include (1) pumping directly into the water and (2) pumping through an eductor which draws in additional water for dilution of the hypochlorite solution.

Answers to questions on page 274.

7.4C The primary advantage of vacuum system chlorinators is safety. If a failure or breakage occurs in the vacuum system, the chlorinator either stops the flow of chlorine into the equipment or allows air to enter the vacuum system rather than allowing chlorine to escape into the surrounding atmosphere.

7.4D The rate of gas flow in a chlorinator is measured by the use of a rotameter.

Answers to questions on page 290.

7.4E Plastic containers are commonly used to store hypochlorite.

7.4F Normally, a week's supply of hypochlorite should be available.

7.4G The upper valve discharges chlorine gas, and the lower valve discharges liquid chlorine from ton chlorine tanks.

7.4H The fusible plug is a safety device. The fusible metal softens or melts at 158° to 165°F (70° to 74°C) to prevent buildup of excessive pressures and the possibility of rupture due to fire or high surrounding temperatures.

Answers to questions on page 290.

7.4I A sling can be used to hold the tubing from flopping around and getting kinked or getting dirt inside.

7.4J One-ton chlorine tanks are placed on their sides with the valves in a vertical position so either chlorine gas or liquid chlorine may be removed.

Answers to questions on page 296.

7.4K A chlorine residual of 0.2 mg/*L* should be found in the most remote part of the distribution system.

7.4L At the upper end of its operating range, the frequency of the strokes or pulses of a hypochlorite pump will be close together and the chlorine will be fed continuously to the water being treated.

Answers to questions on page 298.

7.4M When starting a gas chlorinator, inspect all valves and joints for leaks by placing an ammonia-soaked rag near each valve and joint. The formation of a white cloud or vapor will indicate a chlorine leak.

7.4N The following steps should be performed when shutting down a chlorinator for a long time period.

1. Close chlorine container gas outlet valve.
2. Allow chlorine gas to completely evacuate the system through the injector.
3. Close chlorinator gas discharge valve.
4. Turn off chlorinator power switch, lock out and tag.
5. Secure chlorinator gas manifold and chlorinator valve in closed position.

7.4O Before attempting to start any chlorination system, read the operation and maintenance instructions for your plant and the manufacturer's literature to become familiar with the equipment. Review the plans or drawings of the facility. Determine what equipment, pipelines, pumps, tanks and valves are to be placed into service or are in service. The current status of the entire system must be known before starting or stopping any portion of the system.

Answers to questions on page 301.

7.4P Normal operation of a chlorinator includes daily inspection of container storage area, evaporators, and chlorinators, including injectors.

7.4Q Evaporators are used to convert liquid chlorine to gaseous chlorine for use by gas chlorinators.

7.4R Abnormal conditions that could be encountered when operating an evaporator include, (1) too low a water level, (2) low water temperatures, and (3) no chlorine gas flow to chlorinator.

7.4S The chlorine residual analyzer can be tested by measuring the chlorine residual and comparing this result with actual residual indicated by analyzer.

7.4T Possible chlorinator abnormal conditions include (1) chlorine leaks, (2) chlorine gas pressure too low, (3) injector vacuum too low, and (4) chlorine residual too low.

Answers to questions on page 303.

7.4U The suggested free chlorine residual for treated water is 0.5 mg/*L* at a point just below postchlorination.

7.4V The suggested free chlorine residual for the farthest point in the distribution system is 0.2 mg/*L*.

7.4W To determine if you were chlorinating at the breakpoint, increase the chlorinator feed rate. If the increase in the free chlorine residual is the same as the increased dosage, then you were chlorinating at or past the breakpoint.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 307.

7.5A If chlorine is escaping from a cylinder as a liquid, turn the cylinder so that the leak is on top and the chlorine will escape as a gas.

7.5B Chlorine leaks around valve stems can often be stopped by closing the valve or tightening the packing gland nut. Tighten the nut or stem by turning it clockwise.

7.5C Chlorine leaks at the valve discharge outlet can often be stopped by replacing the gasket or adapter connection.

Answers to questions on page 308.

7.5D Chlorinators should be in a separate room because chlorine gas leaks can damage equipment and are hazardous to operators.

7.5E The weights of chlorine containers should be recorded at the same time every day.

7.5F Adequate ventilation is important in a chlorinator room to remove any leaking chlorine gas that would be hazardous to personnel and damaging to equipment.

7.5G Chlorination rates can be checked by the use of scales and recorders to measure weight loss.

Answers to questions on page 308.

7.6A To produce chlorine dioxide in an existing chlorination system, a diaphragm pump, solution tank, mixer, chlorine dioxide generating tower and electrical controls are also needed.

7.6B Special precautions must be taken when handling sodium chlorite. Spills must be neutralized immediately. Sodium chlorite is very combustible around organic compounds. If sodium chlorite comes in contact with clothing, the clothes should be removed immediately and soaked in water to remove all traces of sodium chlorite or they should be burned immediately.

Answers to questions on page 311.

7.7A Chlorine residual is measured in treated water by the use of (1) amperometric titration and (2) DPD colorimetric method.

7.7B Residual chlorine measurements of treated water should be taken three times per day on small systems and once every two hours on large systems.

Answers to questions on page 315.

7.8A Chlorine gas is extremely toxic and corrosive in moist atmospheres.

7.8B A properly fitting self-contained air or oxygen supply type of breathing apparatus, pressure demand, or rebreather kits are used when repairing a chlorine leak.

7.8C First aid measures depend on the severity of the contact. Move the victim away from the gas area, remove contaminated clothes and keep the victim warm and quiet. Call a doctor and fire department immediately. Keep the patient breathing.

Answers to questions on page 322.

7.9A The operators of ultraviolet disinfection systems must be sure that maximum design turbidity levels and flows are not exceeded. Also bacteriological tests must be made frequently to be assured that adequate disinfection is being achieved.

7.9B Ozone is normally prepared on site because it is very unstable.

7.9C Ozone is less of a hazard than gaseous chlorine due to the fact that chlorine is normally manufactured elsewhere and delivered to the plant site. Ozone is produced on the site, it is used in low concentrations, and it is not stored under pressure. Problem leaks can be stopped by turning the unit off.

Answers to questions on page 326.

7.10A **KNOWN**		**UNKNOWN**
Chlorine Dose, mg/*L*	= 2.0 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L*	= 0.2 mg/*L*	

Calculate the chlorine demand in mg/*L*.

$$\begin{aligned}\text{Chlorine Demand, mg/}L &= \text{Chlorine Dose, mg/}L - \text{Chlorine Residual, mg/}L\\ &= 2.0\text{ mg/}L - 0.2\text{ mg/}L\\ &= 1.8\text{ mg/}L\end{aligned}$$

7.10B **KNOWN**		**UNKNOWN**
Pump Flow, GPM	= 600 GPM	Chlorinator Setting, lbs Chlorine/24 hrs
Chlorine Dose, mg/*L*	= 4.0 mg/*L*	

1. Convert pump flow to million gallons per day (MGD).

$$\text{Flow, MGD} = (600\text{ GPM})\left[\frac{(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{(1{,}000{,}000)}\right]$$

$$= 0.864\text{ MGD}$$

2. Calculate the chlorinator setting in pounds of chlorine per 24 hours.

$$\begin{aligned}\text{Chlorinator Setting, lbs/24 hrs} &= (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})\\ &= (0.864\text{ MGD})\left(\frac{4.0\text{ lbs Chlorine}}{1\text{ M lbs Water}}\right)(8.34\text{ lbs/gal})\\ &= 28.8\text{ lbs chlorine/day}\\ &= 28.8\text{ lbs chlorine/24 hrs}\end{aligned}$$

7.10C **KNOWN**		**UNKNOWN**
Hypochlorinator,	= 60 GPD	Chlorine Dose, mg/*L*
Hypochlorite, %	= 2%	
Pump, GPM	= 400 GPM	

1. Convert the pumping rate to MGD.

$$\text{Pumping Rate, MGD} = (400\text{ GPM})\left[\frac{(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{(1{,}000{,}000)}\right]$$

$$= 0.58\text{ MGD}$$

2. Calculate the chlorine dose rate in pounds per day.

$$\begin{aligned}\text{Chlorine Dose, lbs/day} &= \frac{(\text{Flow, gal/day})(\text{Hypochlorite, \%})(8.34\text{ lb/gal})}{100\%}\\ &= \frac{(60\text{ GPD})(2\%)(8.34\text{ lbs/gal})}{100\%}\\ &= 10.0\text{ lbs chlorine/day}\end{aligned}$$

3. Estimate the chlorine dose in mg/*L*.

$$\begin{aligned}\text{Chlorine Dose, mg/}L &= \frac{\text{Chlorine Dose, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}\\ &= \frac{10.0\text{ lbs chlorine/day}}{(0.58\text{ MGD})(8.34\text{ lbs/gal})}\\ &= 2.1\text{ lbs chlorine/M lbs water}\\ &= 2.1\text{ mg/}L\end{aligned}$$

OBJECTIVE TEST

Chapter 7. DISINFECTION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Highly turbid waters have little influence on the efficiency of disinfecting chemicals.
   1. True
   2. False
2. The higher the temperature of the water, the lower the effectiveness of the disinfectant.
   1. True
   2. False
3. Chlorine gas is lighter than air.
   1. True
   2. False
4. HOCl has a greater disinfection potential than OCl^-.
   1. True
   2. False
5. Free available residual chlorine has the greatest disinfecting action of the chlorine compounds.
   1. True
   2. False
6. Whenever a new chlorine connection is made, always use a new gasket.
   1. True
   2. False
7. The rate of chlorine flow in a chlorinator may be controlled by an orifice.
   1. True
   2. False
8. Hypochlorite is delivered to water treatment plants in 100- to 150- pound cylinders.
   1. True
   2. False
9. The protective cap should always be replaced when moving a chlorine cylinder.
   1. True
   2. False
10. Hypochlorinators with sealed systems are easily repaired in the field.
    1. True
    2. False
11. 150-pound chlorine cylinders may be stored on their sides.
    1. True
    2. False
12. Outlet threads on chlorine container valves are tapered pipe threads.
    1. True
    2. False
13. Operators should look at least once per shift for chlorine and chemical leaks.
    1. True
    2. False
14. Chlorine leaks must be taken care of immediately or they will become worse.
    1. True
    2. False
15. Whenever a new chlorination system is tested for leaks, at least one chlorinator should be on line to withdraw chlorine from the system in case of a leak.
    1. True
    2. False
16. Repairs of small chlorine leaks in equipment may be attempted while the equipment is in service.
    1. True
    2. False
17. Trihalomethanes are formed when disinfecting with chlorine dioxide.
    1. True
    2. False
18. Because of its sharp odor, chlorine gas is considered less hazardous than carbon monoxide or hydrogen sulfide.
    1. True
    2. False
19. Ozone is very stable.
    1. True
    2. False
20. Ozone residuals are measured by the amperometric method.
    1. True
    2. False

MULTIPLE CHOICE

21. Water treatment processes used to remove pathogenic organisms include
    1. Coagulation.
    2. Disinfection.
    3. Filtration.
    4. Screens.
    5. Sedimentation.

22. Chlorine is the most widely used disinfectant because chlorine
    1. Is easily obtained.
    2. Is relatively cheap.
    3. Leaks do not cause a health hazard.
    4. Leaves a residual that can be measured.
    5. Produces no adverse compounds.

[illegible] Calcium hypochlorite may be used as a disinfectant because of its
1. Availability.
2. Calcium content.
3. Explosive nature.
4. Effectiveness as a disinfectant.
5. Sludge-forming characteristics.

24. The purposes of prechlorination include
    1. Control of formation of mud balls.
    2. Control of algae and slime growths.
    3. Improvement of coagulation.
    4. Prevention of formation of trihalomethanes.
    5. Reduction of tastes and odors.

25. Which of the following items should be on the normal operation and maintenance checklist for a hypochlorinator?
    1. Clean up area
    2. Hour meter on water pump
    3. Lubrication
    4. Operation of equipment
    5. Solution level

26. One-ton chlorine tanks
    1. Have fusible plugs located at valves.
    2. Must be stored in an upright position.
    3. Remove liquid chlorine from the top valve.
    4. Use the bottom valve only with chlorine evaporators.
    5. Should have locking devices to prevent the tanks from rolling when connected.

27. Daily tasks when operating a hypochlorinator include
    1. Check operation of chemical feed pump.
    2. Check residual of chlorine in system.
    3. Inspect building to be sure that only authorized personnel have entered the building.
    4. Read and record level of solution tank.
    5. Read meters and record water pumped.

28. Which of the following tasks should be performed before starting a chlorination system?
    1. Become familiar with equipment.
    2. Determine which valves should be opened and closed.
    3. Inspect all tubing, manifold and valve connections for potential leaks.
    4. Read manufacturer's instructions.
    5. Turn off injector water supply.

29. Which of the following tasks should be performed daily in the chlorine storage area?
    1. Be sure all chlorine containers are properly secured.
    2. Be sure fan and ventilation equipment are operating properly.
    3. Inspect building or area for ease of access by authorized personnel.
    4. Read scales, charts and meters at the same time every day.
    5. Try to maintain temperature of storage area below temperature of chlorinator room.

30. Chlorine leaks
    1. Around valve stems may be stopped by tightening the packing gland nut.
    2. Around valve stems may be stopped by closing the valve.
    3. At the discharge outlet may be stopped by replacing the gasket.
    4. At the discharge outlet may be stopped by replacing the adapter connection.
    5. May be stopped by spraying water on the leak.

31. Which of the following items should be included in a chlorine safety program?
    1. Establishment of a maintenance and calibration program for safety devices and equipment
    2. Establishment and implementation of a safety program
    3. Establishment of emergency procedures for chlorine leaks and first aid
    4. Periodic hands-on training using safety equipment
    5. Written rules

32. Chlorine gas is
    1. Corrosive in moist atmospheres.
    2. Extremely toxic.
    3. Fatal at high exposures.
    4. Irritating to the mucous membranes.
    5. Lighter than air.

33. Estimate the chlorine demand of a water that is dosed at 3.0 mg/*L*. The chlorine residual is 0.5 mg/*L* after a 30-minute contact period.
    1. 0.5 mg/*L*
    2. 2.5 mg/*L*
    3. 3.0 mg/*L*
    4. 3.5 mg/*L*
    5. 5.0 mg/*L*

34. What should be the setting on a chlorinator (lbs chlorine per 24 hours) if a pump usually delivers 500 GPM and the desired chlorine dosage is 3.0 mg/*L*?
    1. 2 lbs chlorine/24 hours
    2. 18 lbs chlorine/24 hours
    3. 25 lbs chlorine/24 hours
    4. 28 lbs chlorine/24 hours
    5. 50 lbs chlorine/24 hours

35. At 9:00 am on Wednesday morning a chlorine cylinder weighs 72 pounds. At 9:00 am on Thursday morning the same cylinder weighs 54 pounds. What is the chlorinator feed rate in pounds per 24 hours?
    1. 0.75 lbs per 24 hours
    2. 1.33 lbs per 24 hours
    3. 18 lbs per 24 hours
    4. 54 lbs per 24 hours
    5. 72 lbs per 24 hours

36. Estimate the chlorine dose in mg/*L* if a chlorinator feeds at a rate of 21 lbs per 24 hours and the flow is 0.60 MGD.
    1. 0.25 mg/*L*
    2. 0.42 mg/*L*
    3. 2.5 mg/*L*
    4. 3.5 mg/*L*
    5. 4.2 mg/*L*

37. Water from a well is being treated by a hypochlorinator. If the hypochlorinator is set at a pumping rate of 25 gallons per day (GPD) and uses a two-percent available chlorine solution, what is the chlorine dose in mg/*L* if the pump delivers 140 GPM?
    1. 1.0 mg/*L*
    2. 1.5 mg/*L*
    3. 2.0 mg/*L*
    4. 2.5 mg/*L*
    5. 3.0 mg/*L*

38. Estimate the water velocity in a channel in feet per second if a float travels 20 feet in 5 seconds.
    1. 0.2 ft/sec
    2. 0.25 ft/sec
    3. 2 ft/sec
    4. 4 ft/sec
    5. 5 ft/sec

39. Estimate the water flow rate in an open channel in cubic feet per second (cfs) if the channel is four-feet wide, the water depth is 2.5 feet, and the water velocity is two feet per second.
    1. 0.2 cu ft/sec
    2. 2 cu ft/sec
    3. 5 cu ft/sec
    4. 10 cu ft/sec
    5. 20 cu ft/sec

40. Estimate the water flow rate in a 24-inch diameter pipe in gallons per minute (GPM) when the flow velocity is three feet per second.
    1. 1.17 GPM
    2. 3.14 GPM
    3. 6.28 GPM
    4. 9.42 GPM
    5. 46.97 GPM

End of Objective Test

CHAPTER 8

CORROSION CONTROL

by

Jack Rossum

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OBJECTIVES

Chapter 8. CORROSION CONTROL

Following completion of Chapter 8, you should be able to:

1. Recognize adverse effects of corrosion,
2. Describe how a pipe corrodes,
3. Determine if corrosion problems exist in your system,
4. Determine if a water is saturated with calcium carbonate,
5. Select the proper chemical to control corrosion,
6. Determine the proper chemical dose to control corrosion,
7. Use cathodic protection to control corrosion,
8. Prevent soil corrosion (external corrosion), and
9. Troubleshoot and solve corrosion problems.

GLOSSARY

Chapter 7. DISINFECTION

ALKALINITY (AL-ka-LIN-it-tee) ALKALINITY

The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

AMPERAGE (AM-purr-age) AMPERAGE

The strength of an electric current measured in amperes. The amount of electric current flow similar to the flow of water in gallons per minute.

AMPERE (AM-peer) AMPERE

The unit used to measure current strength. The current produced by an electromotive force of one volt acting through a resistance of one ohm.

ANAEROBIC (AN-air-O-bick) ANAEROBIC

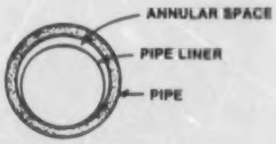
A condition in which "free" (atmospheric) or dissolved oxygen is *NOT* present in water.

ANION (AN-EYE-on) ANION

A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of a difference in electrical potential. Chloride (Cl^-) is an anion.

ANNULAR SPACE (AN-you-ler) ANNULAR SPACE

A ring-shaped space located between two circular objects, such as two pipes.



ANODE (an-O-d) ANODE

The positive pole of an electrolytic system, such as a battery. The anode attracts negatively charged particles or ions (anions).

ATOM ATOM

The smallest unit of a chemical element; composed of protons, neutrons and electrons.

BASE METAL BASE METAL

A metal (such as iron) which reacts with dilute hydrochloric acid to form hydrogen. Also see NOBLE METAL.

C FACTOR C FACTOR

A factor or value used to indicate the smoothness of the interior of a pipe. The higher the C Factor, the smoother the pipe, the greater the carrying capacity, and the smaller the friction or energy losses from water flowing in the pipe. To calculate the C Factor, measure the flow, pipe diameter, distance between two pressure gages, and the friction or energy loss of the water between the gages.

$$\text{C Factor} = \frac{\text{Flow, GPM}}{193.75\ (\text{Diameter, ft})^{2.63}\ (\text{Slope})^{0.54}}$$

CATALYST (CAT-uh-LIST) CATALYST

A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.

CATALYZE (CAT-uh-LIZE) CATALYZE

To act as a catalyst. Or, to speed up a chemical reaction.

CATHODE (KA-thow-d) CATHODE

The negative pole or electrode of an electrolytic cell or system. The cathode attracts positively charged particles or ions (cations).

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic. This concentrates corrosion on auxiliary anodic parts which are deliberately allowed to corrode, instead of letting the structure corrode.

CATION (CAT-EYE-en) CATION

A positive charged ion in an electrolyte solution, attracted to the cathode under the influence of a difference in electrical potential. Sodium ion (Na^+) is a cation.

COMPOUND COMPOUND

A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride — NaCl) is a compound.

CORROSION CORROSION

The gradual decomposition or destruction of a material by chemical action, often due to an electrochemical reaction. Corrosion may be caused by (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, or (3) differential-concentration cells. Corrosion starts at the surface of a material and moves inward.

CORROSION INHIBITORS CORROSION INHIBITORS

Substances that slow the rate of corrosion.

CORROSIVITY CORROSIVITY

An indication of the corrosiveness of a water. The corrosiveness of a water is described by the water's pH, alkalinity, hardness, temperature, total dissolved solids, and the Langelier Index.

COUPON COUPON

A steel specimen inserted into water to measure the corrosiveness of water. The rate of corrosion is measured as the loss of weight of the coupon (in milligrams) per surface area (in square decimeters) exposed to the water per day. 10 decimeters = 1 meter = 100 centimeters.

CURRENT CURRENT

A movement or flow of electricity. Water flowing in a pipe is measured in gallons per second past a certain point, not by the number of water molecules going past a point. Electric current is measured by the number of coulombs per second flowing past a certain point in a conductor. A coulomb is equal to about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons). A flow of one coulomb per second is called one ampere, the unit of the rate of flow of current.

DEAD END DEAD END

The end of a water main which is not connected to other parts of the distribution system by means of a connecting loop of pipe.

ELECTROCHEMICAL REACTION ELECTROCHEMICAL REACTION

Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external force and cause the reaction, such as electrolysis caused by a D.C. (direct current) electric railway, or the electron flow may be caused by a chemical reaction as in the galvanic action of a flashlight dry cell.

ELECTROCHEMICAL SERIES ELECTROCHEMICAL SERIES

A list of metals with the standard electrode potentials given in volts. The size and sign of the electrode potential indicates how easily these elements will take on or give up electrons or corrode. Hydrogen is arbitrarily assigned a value of zero.

ELECTROLYSIS (e-leck-TRAWL-uh-sis) ELECTROLYSIS

The decomposition of material by an outside electrical current.

ELECTROLYTE (ee-LECK-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROLYTIC CELL (ee-LECK-tro-LIT-ick) ELECTROLYTIC CELL

A device in which the chemical decomposition of material causes an electric current to flow. Also, a device in which a chemical reaction occurs as a result of the flow of electric current. Chlorine and caustic (NaOH) are made from salt (NaCl) in electrolytic cells.

ELECTROMOTIVE FORCE (E.M.F.) ELECTROMOTIVE FORCE (E.M.F.)

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See VOLTAGE.

ELECTROMOTIVE SERIES ELECTROMOTIVE SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the Galvanic Series. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

ELECTRON ELECTRON

An extremely small negatively-charged particle; the part of an atom that determines its chemical properties.

ELEMENT ELEMENT

A substance which cannot be separated into its constituent parts and still retain its chemical identity. For example, sodium (Na) is an element.

GALVANIC CELL GALVANIC CELL

An electrolytic cell capable of producing electrical energy by electrochemical action. The decomposition of materials in the cell causes an electric (electron) current to flow from cathode to anode.

GALVANIC SERIES GALVANIC SERIES

A list of metal and alloys presented in the order of their tendency to corrode (or go into solution). Also called the ELECTROMOTIVE SERIES. This is a practical application of the theoretical ELECTROCHEMICAL SERIES

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

A chemical reaction in which a compound is converted into another compound by taking up water.

INTERFACE INTERFACE

The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

ION ION

An electrically charged atom, radical (such as SO_4^{2-}), or molecule formed by the loss or gain of one or more electrons.

LANGELIER INDEX (L.I.) LANGELIER INDEX (L.I.)

An index reflecting the equilibrium pH of a water with respect to calcium and alkalinity. This index is used in stabilizing water to control both corrosion and the deposition of scale.

$$\text{Langelier Index} = \text{pH} - \text{pH}_s$$

where pH = actual pH of the water, and

pH_s = pH at which the water is just saturated with calcium carbonate.

LOGARITHM (LOG-a-rith-m) LOGARITHM

The exponent that indicates the power to which a number must be raised to produce a given number. For example: if $B^2 = N$, the ^{2} is the logarithm of N (to the base B), or $10^2 = 100$ and $\log_{10} 100 = 2$. Also abbreviated to "log."

MECHANICAL JOINT MECHANICAL JOINT

A flexible device that joins pipes or fittings together by the use of lugs and bolts.

MOLECULE (MOLL-uh-KULE) MOLECULE

The smallest division of a compound that still retains or exhibits all the properties of the substance.

NOBLE METAL NOBLE METAL

A chemically inactive metal (such as gold). A metal that does not corrode easily and is much scarcer (and more valuable) than the so-called useful or base metals. Also see BASE METAL.

OHM OHM

The unit of electrical resistance. The resistance of a conductor in which one volt produced a current of one ampere.

OXIDIZING AGENT — OXIDIZING AGENT

Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a REDUCING AGENT.

pH (pronounce as separate letters) — pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$pH = \text{Log}\,\frac{1}{(H^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 is most basic, and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5.

REDUCING AGENT — REDUCING AGENT

Any substance, such as a base metal (iron) or the sulfide ion (S^{2-}), that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REPRESENTATIVE SAMPLE — REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

SALINITY — SALINITY

(1) The relative concentration of dissolved salts, usually sodium chloride, in a given water.

(2) A measure of the concentration of dissolved mineral substances in water.

SATURATION — SATURATION

The condition of a liquid (water) when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

SLAKE — SLAKE

To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.

SLURRY (SLUR-e) — SLURRY

A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SUPERSATURATED — SUPERSATURATED

An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.

TITRATE (TIE-trate) — TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction as signaled by the end point.

TUBERCLE (TOO-burr-cull) — TUBERCLE

A protective crust of corrosion products (rust) which builds up over a pit caused by the loss of metal due to corrosion.

TUBERCULATION (too-BURR-que-LAY-shun) — TUBERCULATION

The development or formation of small mounds of corrosion products (rust) on the inside of iron pipe. These mounds (tubercles) increase the roughness of the inside of the pipe thus increasing resistance to water flow (increases the C Factor).

VOLTAGE — VOLTAGE

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See ELECTROMOTIVE FORCE (E.M.F.)

CHAPTER 8. CORROSION CONTROL

(Lesson 1 of 2 Lessons)

8.0 ADVERSE EFFECTS OF CORROSION[1]

Corrosive water can cause very serious problems in both water supply facilities and water treatment plants. Economic losses resulting from corrosion damage can be very large. Water main replacement is often required when *TUBERCULATION*[2] reduces the carrying capacity of a main. Tuberculation increases pipe roughness which causes an increase in pump energy costs and may reduce distribution system pressures. Leaks in water mains are usually caused by corrosion and may eventually require the replacement of a water main. Figure 8.1 shows corrosion damage to pipes due to corrosive soils.

Many other serious problems are caused by corrosive water. Corrosive water causes materials to deteriorate and go into solution (be carried by the water). Corrosion of toxic metal pipe materials such as lead can create a serious health hazard. Corrosion of iron may produce a flood of unpleasant telephone calls from consumers complaining about rusty water, stained laundry and bad tastes. Corrosive drinking water causes internal corrosion (the inside of the pipe corrodes) and corrosive soils and moisture cause external corrosion (the outside of the pipe corrodes).

8.1 CHEMISTRY OF CORROSION INSIDE PIPES

In this chapter we want to learn what causes corrosion and how to control corrosion. To help you understand and identify the causes of corrosion, we are going to use a *GALVANIC CELL*[3]. The situations that we can study using a galvanic cell are the same situations encountered by water mains and treatment facilities in the field. By studying conditions in which electrons flow in a galvanic cell, we can observe the conditions which cause electron flow and result in the corrosion of materials in the field. Once we understand the causes of corrosion, we can evaluate and select solutions for controlling corrosion problems.

8.10 The Galvanic Cell

In this section we are going to explain the corrosion reaction so you can (1) understand what causes corrosion, and (2) select the proper procedures to control corrosion.

Metallic (metal) corrosion in potable water is *ALWAYS* the result of an *ELECTROCHEMICAL REACTION*[5]. An electrochemical reaction is a chemical reaction where the flow of electric current[6] itself is an essential part of the reaction. If the electric current is stopped by breaking the circuit, the chemical reaction will stop. Also, if the chemical reaction is stopped by removing one of the reacting chemicals, the flow of electric current will stop. For corrosion to occur, both of these factors — electrical current and chemical reaction — must be present.

You might already be familiar with the electrochemical reaction that takes place in flashlight dry cells (batteries). When a flashlight switch is turned on, an electrical current flows and lights the bulb. At the same time a chemical reaction (usually involving the corrosion of metallic zinc) takes place. If the switch is turned off, the chemical reaction stops. However, if the switch is left on, all of the zinc is used up in a few hours and the current flow stops.

When corrosion occurs, both the electrical and the chemical reactions occur at the same time, but at different locations. These locations are connected to each other by a metallic conductor (the pipe) through which *ELECTRONS*[7] flow. This relationship forms one kind of corrosion cell. A common corrosion cell that is found in water systems and plumbing is called a galvanic cell. This cell occurs when two dissimilar metals such as iron and copper are connected (Figure 8.2).

From time to time in this chapter we will be referring to the galvanic cell in Figure 8.3. The important point to remember is that the greater the current flow through the ammeter, the greater the rate of corrosion if the circumstances existed

---

[1] *Corrosion. The gradual decomposition or destruction of a material by chemical action, often due to an electrochemical reaction. Corrosion may be caused by (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, or (3) differential-concentration cells. Corrosion starts at the surface of a material and moves inward.*

[2] *Tuberculation (too-BURR-que-LAY-shun). The development or formation of small mounds of corrosion products (rust) on the inside of iron pipe. These mounds (tubercules) increase the roughness of the inside of the pipe thus increasing resistance to water flow (increases the C Factor).*

[3] *Galvanic Cell. An ELECTROLYTIC CELL[4] capable of producing electrical energy by electrochemical action. The decomposition of materials in the cell causes an electric (electron) current to flow from cathode to anode.*

[4] *Electrolytic Cell (ee-LECK-tro-LIT-ick). A device in which the chemical decomposition of material causes an electric current to flow. Also, a device in which a chemical reaction occurs as a result of the flow of electric current. Chlorine and caustic (NaOH) are made from salt (NaCl) in electrolytic cells.*

[5] *Electrochemical Reaction. Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action).*

[6] *Also referred to as "electron transfer" from one type of atom to another.*

[7] *Electron. An extremely small, negatively-charged particle; the part of an atom that determines its chemical properties.*

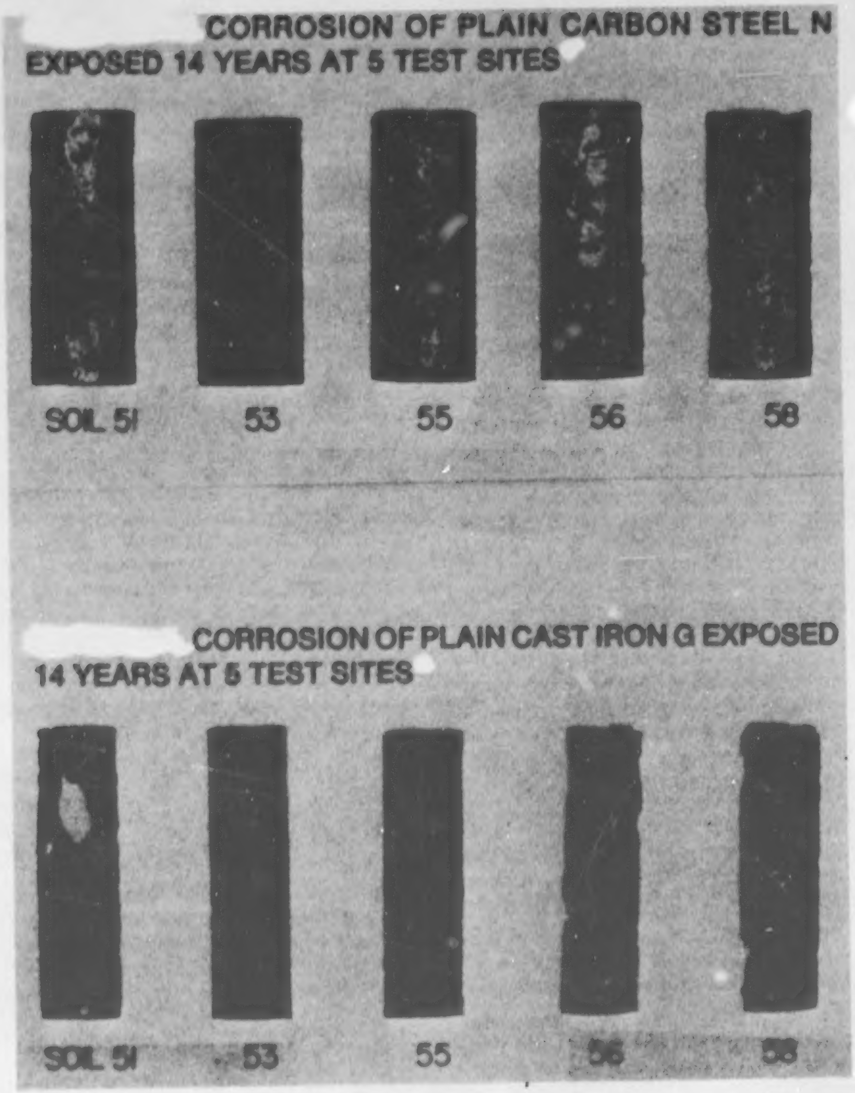

CORROSION OF PLAIN CARBON STEEL N EXPOSED 14 YEARS AT 5 TEST SITES
SOIL 51
53
55
56
58
CORROSION OF PLAIN CAST IRON G EXPOSED 14 YEARS AT 5 TEST SITES
SOIL 51
53
55
56
58

Fig. 8.1 Exterior corrosion due to corrosive soils
(Permission of ARMCO)

with piping or other facilities in the field. Therefore, whatever causes current to flow in the galvanic cell, will also cause current to flow in the field and cause corrosion. If we know what causes corrosion, we can stop the cause or correct the situation and control corrosion.

Figure 8.3 shows a galvanic cell set up so that some electrical measurements can be made. This setup consists of two pieces of metal called electrodes that are placed in water. A voltmeter is connected to measure the voltage between the two electrodes without causing a significant flow of current. When the switch is closed,[8] current flows between the electrodes. This current is measured by an ammeter. In this example, one of the electrodes is copper and the other is iron. Aerated tap water is then added to the jar until the electrodes are almost covered with water.

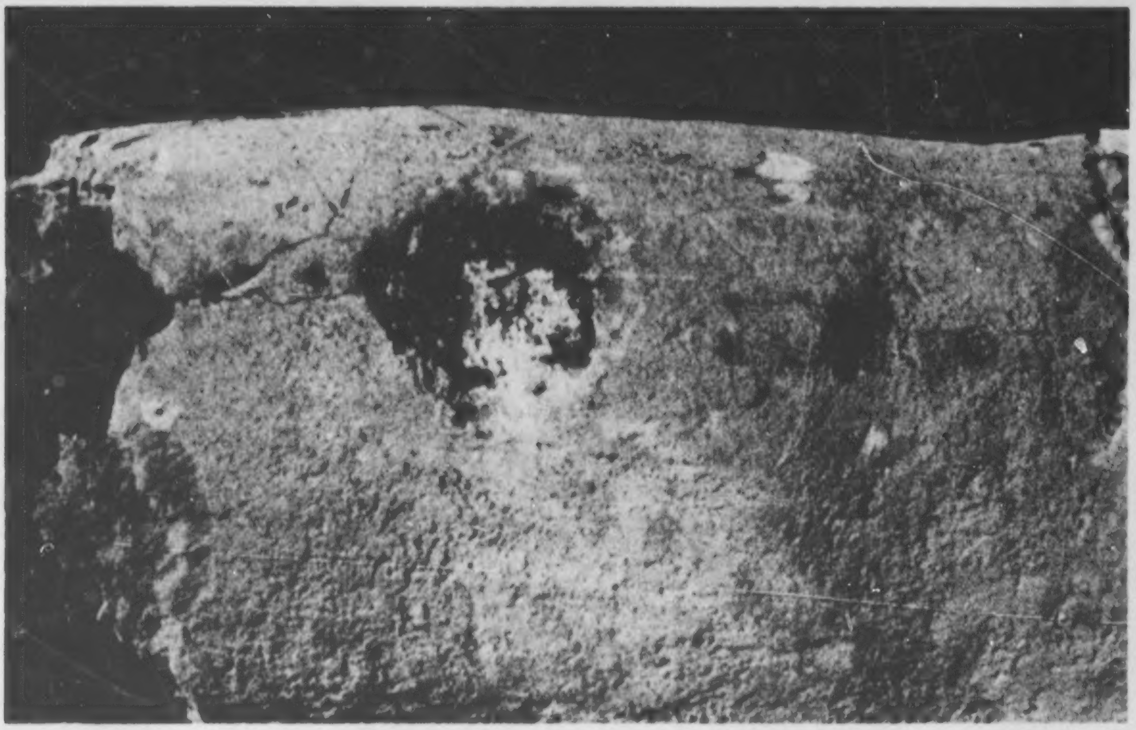
The voltmeter shows a voltage of approximately 0.4 volts between the two electrodes. The copper electrode is the *NEGATIVE* electrode and is called the *CATHODE*[9]. The iron electorde is the *POSITIVE* electrode and called the *ANODE*[10].

---

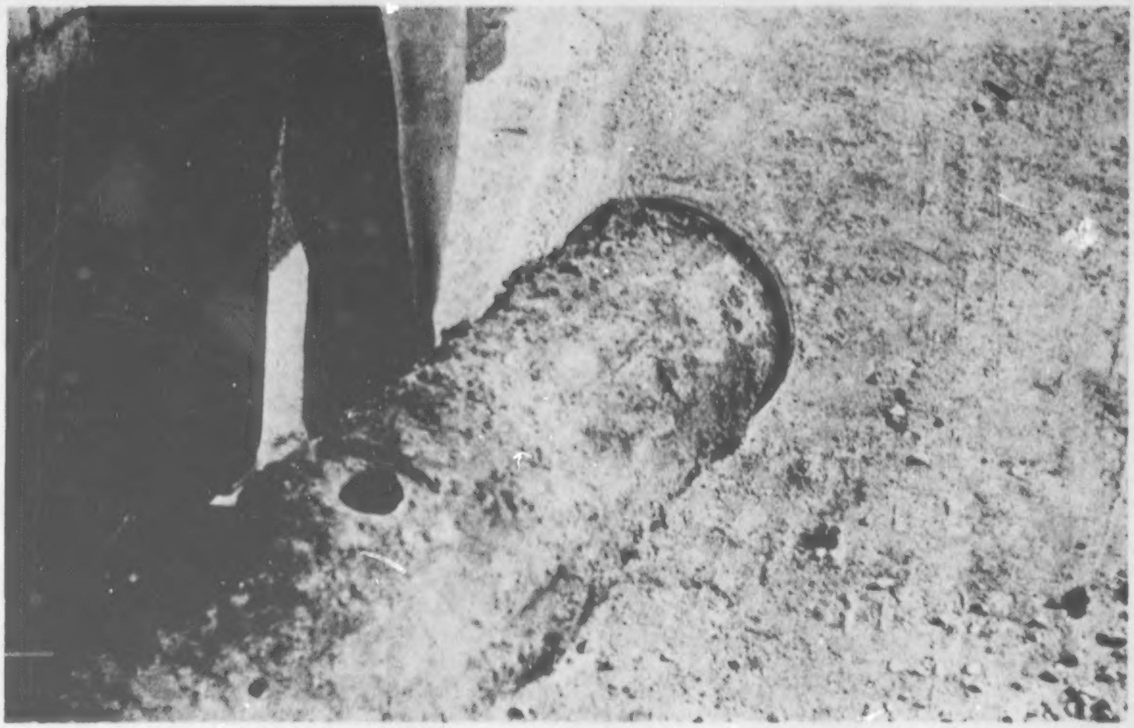
[8] *Electricians often talk about closing an electrical circuit or switch. This means they are closing a switch which actually connects circuits together so electricity can flow through the circuit. Closing an electrical circuit is like opening a valve on a water pipe. The voltmeter is similar to a pressure gage in a water system.*

[9] *Cathode (ca-THOW-d). The negative pole or electrode of an electrolytic cell or system. The cathode attracts positively charged particles or ions (cations).*

[10] *Anode (an-O-d). The positive pole of an electrolytic system, such as a battery. The anode attracts negatively charged particles or ions (anions).*



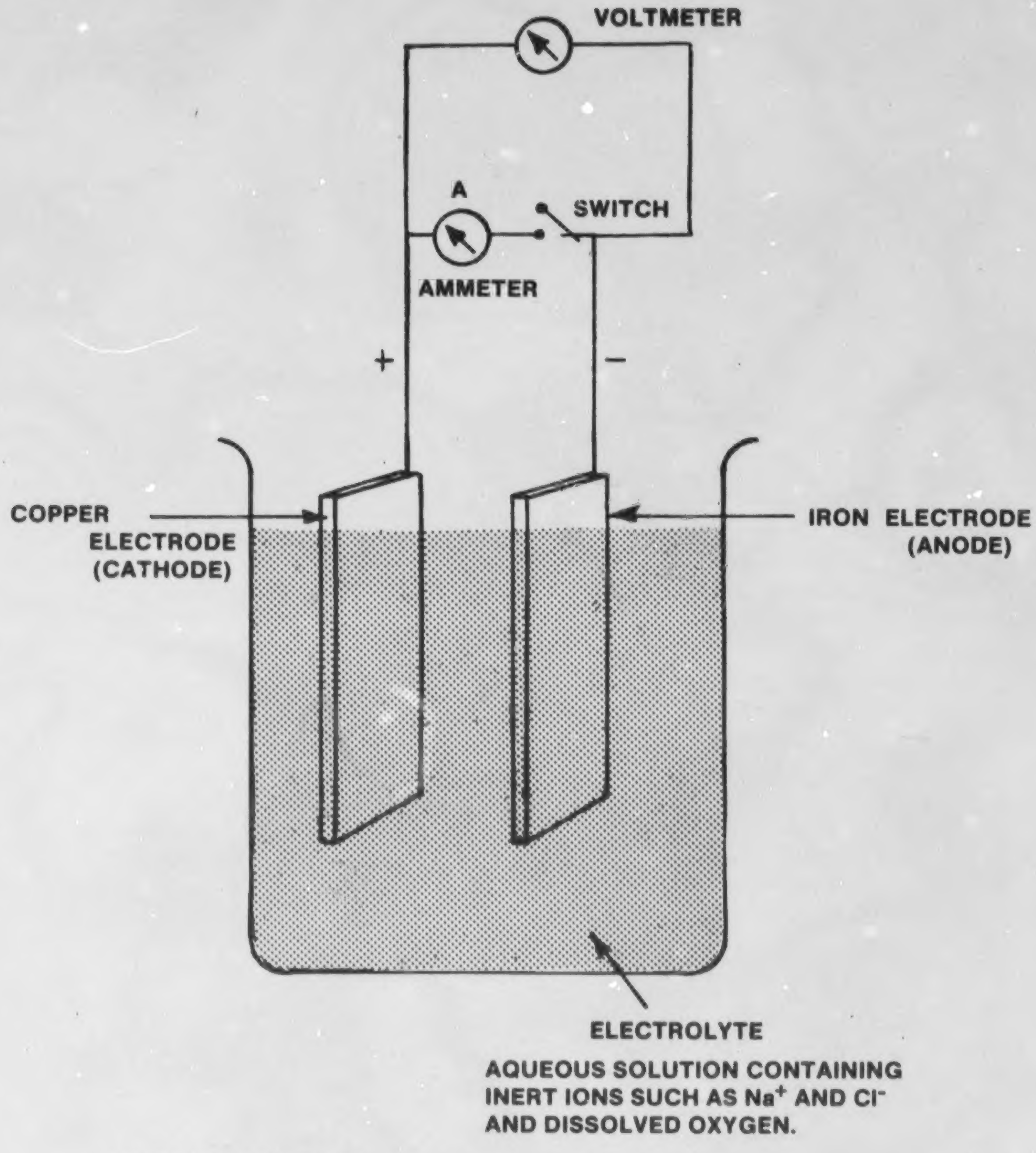
Local galvanic cell



Corrosion at corporation stop hole caused by joining two dissimilar metals

Fig. 8.2 Galvanic cells in water mains

(Permission of ARMCO)


VOLTMETER
A
SWITCH
AMMETER
+
−
COPPER ELECTRODE (CATHODE)
IRON ELECTRODE (ANODE)
ELECTROLYTE
AQUEOUS SOLUTION CONTAINING INERT IONS SUCH AS Na^+ AND Cl^- AND DISSOLVED OXYGEN.

CATHODE REACTION:

$$3O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$$

ANODE REACTION:

$$2Fe \longrightarrow 2Fe^{++} + 4e^-$$

Fig. 8.3 Galvanic Cell

(From *FUNDAMENTALS OF METALLIC CORROSION IN FRESH WATER* by J.R. Rossum. Published by Roscoe Moss Company, Los Angeles, California)

As soon as the switch is closed, the ammeter indicates that a flow of electric current is taking place. The chemical reaction taking place at the anode (iron electrode) is as follows:

$$Fe \rightarrow F2^{2+} + 2\,e^{-}.$$

This chemical equation is simply a sort of shorthand way of saying that uncharged iron *ATOMS*[11] (Fe or iron pipe) change into iron *IONS*[12] (Fe^{2+} iron atoms with a positive electrical charge) and two electrons (e^{-}). Iron ions are soluble in water so when this reaction occurs, the iron metal or pipe is disintegrating or corroding into the water.

At the cathode (copper electrode) the chemical reaction is:

$$O_2 + 4\,e^{-} + 2\,H_2O \rightarrow 4\,OH^{-}.$$

Again, this is chemical shorthand for saying that a *MOLECULE*[13] of oxygen and two molecules of water react with four electrons to form four hydroxide or hydroxyl ions (OH^{-}). Both of these reactions occur at the metal-water *INTERFACE*[14] (where the water touches the metal) because electrons will not flow easily through potable water. Also note that dissolved oxygen must be present for corrosion to occur. Dissolved oxygen is called the *OXIDIZING AGENT*[15] because it accepts the electrons. The material that loses the electrons (in this case the iron) is said to be oxidized. There are many oxidizing agents; however, so far as corrosion in fresh water is concerned, dissolved oxygen is the most important. Whenever water is flowing in a pipe, there is usually plenty of dissolved oxygen present for the corrosion reactions to occur.

Two other oxidizing agents are chlorine and hydrogen. Chlorine is an excellent oxidizing agent and accepts electrons by the following reaction:

$$Cl_2 + 2\,e^{-} \rightarrow 2\,Cl^{-}.$$

In this chemical reaction, molecular chlorine (Cl_2) is converted to chlorine ions (Cl^{-}). Hydrogen ions from acids also act as oxidizing agents and accept electrons as follows:

$$2\,H^{+} + 2\,e^{-} \rightarrow H_2.$$

Although hydrogen ion is extremely active (corrosive) at *pH*[16] values below 6, neither chlorine nor hydrogen ions are usually present in sufficient concentrations in potable water to have a significant effect on corrosion.

Aluminum and, to a lesser extent, zinc may be oxidized by hydroxyl ions:

$$2\,Al + 2\,OH^{-} + 4\,H_2O \rightarrow 2\,H_2AlO_3^{-} + 3\,H_2.$$

For this reason aluminum is unsatisfactory in highly alkaline aquatic environments. Thus, aluminum should never be imbedded directly in concrete without protection, such as a zinc chromate primer.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 369.

8.0A List the problems that can be created by corrosive waters.

8.1A What is an electrochemical reaction?

8.1B What happens to an iron water pipe when the pipe is connected to a copper pipe?

8.1C Why is aluminum unsatisfactory for use in highly alkaline aquatic environments?

8.11 Factors Influencing Corrosion Rate

There are several important factors that influence the corrosion rate of a water main or other facility. Important water quality indicators include dissolved oxygen and *SALINITY*[17]. The cathode metal, any cathode film formation and any zinc compounds added to develop zinc coatings will influence the corrosion rate.

8.110 Dissolved Oxygen

To study the influences of various factors on the rate of corrosion, let's use an experimental galvanic cell shown in Figure 8.4. When the switch is first closed, the current may be several *MILLIAMPS*[18] for each square centimeter of

---

[11] *Atom. The smallest unit of a chemical element; composed of protons, neutrons and electrons.*
Element. A substance which cannot be separated into its constituent parts and still retain its chemical identity. For example, sodium (Na) is an element.

[12] *Ion. An electrically charged atom, radical (such as SO_4^{2-}), or molecule formed by the loss or gain of one or more electrons.*
Electron. An extremely small negatively-charged particle; the part of an atom that determines its chemical properties.

[13] *Molecule (MOLL-uh-KULE). The smallest division of a compound that still retains or exhibits all the properties of the substance.*
Compound. A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride — NaCl) is a compound.

[14] *Interface. The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).*

[15] *Oxidizing Agent. Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a REDUCING AGENT.*
Reducing Agent. Any substance, such as a base metal (iron) or the sulfide ion (S^{2-}), that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

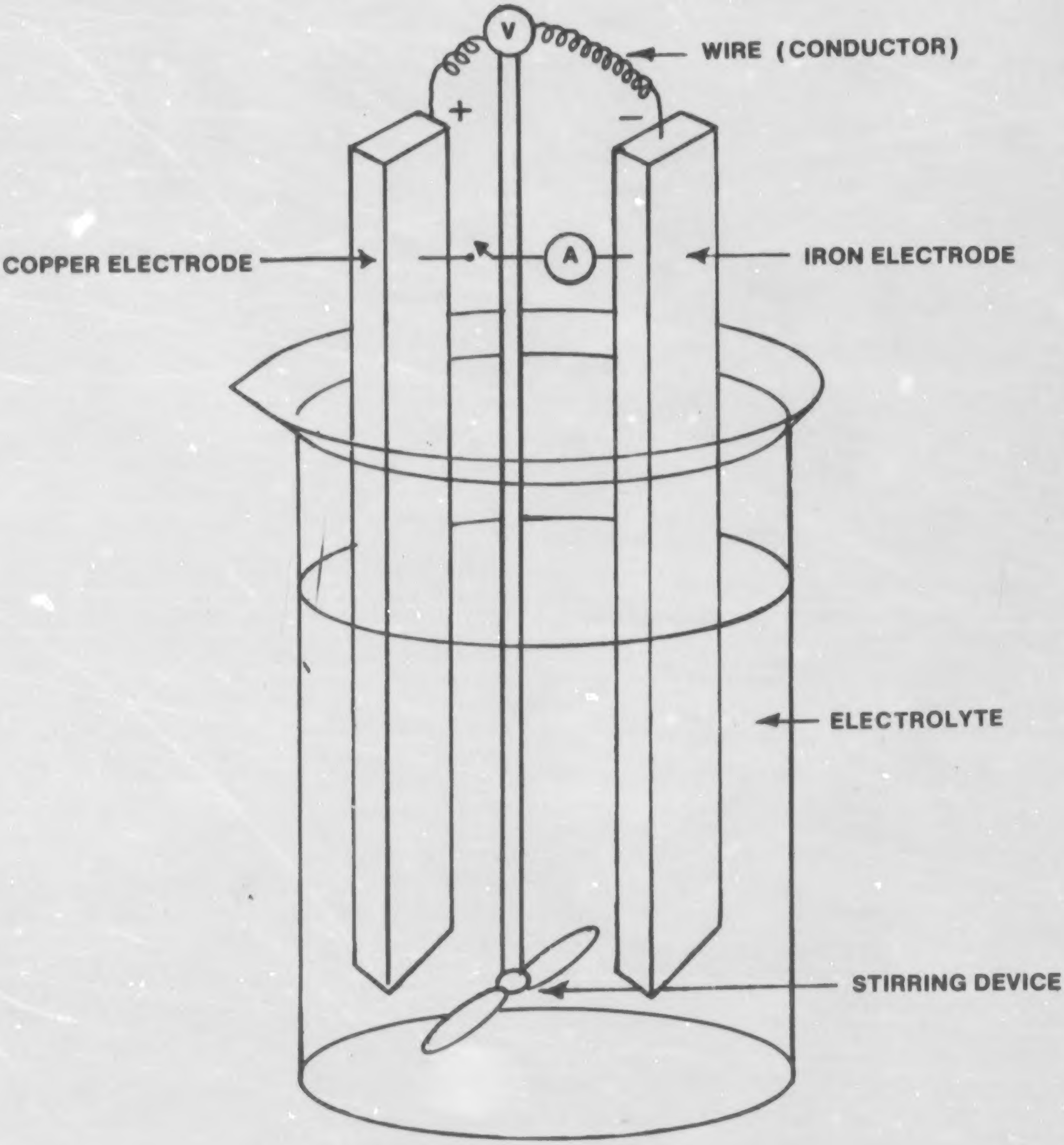
[16] *pH (pronounced as separate letters). pH is an expression of the intensity of the basic or acid condition of a liquid. Mathmetically, pH is the logarithm (base 10) of the reciprocal of the hydrogen-ion activity.*

$$pH = Log \frac{1}{(H^{+})}$$

The pH may range from 0 to 14, where 0 is most acid, 14 is most basic, and 7 is neutral. Natural waters usually have a pH between 6.5 and 8.5
Logarithm (LOG-a-rith-m). The exponent that indicates the power to which a number must be raised to produce a given number. For example: if $B^2 = N$, the 2 is the logarithm of N (to the base B), or $10^2 = 100$ and $\log_{10} 100 = 2$. Also abbreviated to "log."

[17] *Salinity. (1) The relative concentration of dissolved salts, usually sodium chlorine, in a given water. (2) A measure of the concentration of dissolved mineral substances in water.*

[18] *Ampere (AM-peer). The unit used to measure current strength. The current produced by an electromotive force of one volt acting through a resistance of one ohm. A MILLIAMP is one thousandth of an ampere or 0.001 amp.*


V
WIRE (CONDUCTOR)
+
−
COPPER ELECTRODE
A
IRON ELECTRODE
ELECTROLYTE
STIRRING DEVICE

NOTE: Try to visualize the iron electrode as iron pipe and the copper electrode as copper pipe. They are connected by a conductor such as iron pipe or copper pipe which allows the flow of electrons. The conductor here is a wire.

Fig. 8.4 Experimental galvanic cell

electrode area. After a few minutes the current will drop to only a small fraction of its initial value. The reason for this is that the oxygen molecules in the water next to the copper electrode are quickly used up and can only be replenished by the very slow process of diffusion (the movement of oxygen molecules through the water). Even if the water is stirred, there will be a thin layer next to the electrode that is barely moving. The flow of current will be limited by the rate at which oxygen molecules can diffuse through this surface-contact layer.

8.111 Cathode Metal

If the copper electrode (cathode) is replaced with a stainless steel electrode, the open circuit *VOLTAGE*[19] will be almost the same as with the copper, but both the initial and steady state *CURRENTS*[20] will be lower. The easiest way to understand this is to consider that various metals *CATALYZE*[21] the reaction between oxygen and electrons and that copper is a better *CATALYST*[22] than stainless steel. The surface properties of the metal determine the rate of the corrosion reaction, but the metal is not consumed by the reaction.

If other *NOBLE METALS*[23] such as gold, silver or platinum are substituted for copper, the voltage of the cell will be unchanged since the chemical reactions are not changed. If another, more reactive *BASE METAL*,[24] such as magnesium, aluminum or zinc is used in place of iron, the anode reaction is changed and the voltage will be different. Magnesium loses electrons more readily than iron, so a magnesium-copper cell will produce a higher voltage than an iron-copper cell. Table 8.1 is called the *GALVANIC SERIES*[25] in which the most active metals are listed at the top. This list is related to, but somewhat different from the *ELECTROCHEMICAL SERIES*[26] which is important in chemical theory.

TABLE 8.1 GALVANIC SERIES

	Galvanic Series
ANODE	Magnesium
	Zinc
	Aluminum (2S)
	Cadmium
	Aluminum (175T)
	Steel or Iron
	Cast Iron
	Lead — Tin Solder
	Lead
	Nickel
	Brasses
	Copper
	Bronzes
	Stainless Steel (304)
	Monel
	Stainless Steel (316)
	Silver
	Graphite
CATHODE	Gold

If a steel nail is immersed in a solution of a copper salt, such as a solution of bluestone or copper sulfate ($CuSO_4 \cdot 5 H_2O$), metallic copper will be formed or "plate-out" on the surface of the nail. In the same manner, if a reservoir has been treated with bluestone to control algal growths, there is a possibility that copper will later plate out on steel pipes in the distribution system. The metallic copper might then act as a cathode in a galvanic cell and cause corrosion of the steel.

A similar phenomenon occurs in the so-called "dezincification" of brass. Brass is an alloy of zinc and copper. When brass corrodes, the result is a mass of spongy copper having nearly the same shape as the original brass. For a long time people believed that the zinc dissolved and left the copper. Today we know that the alloy itself dissolves and, since the copper is more noble (less reactive) than the brass, the copper plates out in more or less its original position.

To illustrate the impact of dissolved oxygen on corrosion, look again at the experimental galvanic cell in Figure 8.4. Assume that we start the stirrer and, when a steady-state current has been reached, we bubble a stream of pure oxygen gas into the water. This will gradually cause the dissolved oxygen concentration in the water to gradually increase. When the oxygen concentration has doubled, the current and therefore the corrosion rate will also have doubled. The current is said to be directly proportional to the dissolved oxygen concentration. That is, an increase of one unit of dissolved oxygen will produce an incease of one unit of current.

---

[19] *Voltage. The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed.*

[20] *Current. A movement or flow of electricity.*

[21] *Catalyze (CAT-uh-LIZE). To act as a catalyst. Or, to speed up a chemical reaction.*

[22] *Catalyst (CAT-uh-LIST). A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.*

[23] *Noble Metal. A chemically inactive metal. A metal that does not corrode easily and is much scarcer (and more valuable) than the so-called useful or base metals.*

[24] *Base Metal. A metal (such as iron) that reacts with dilute hydrochloric acid to form hydrogen.*

[25] *Galvanic Series. A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the Electromotive Series. This is a practical application of the theoretical Electrochemical Series.*

[26] *Electrochemical Series. A list of metals with the standard electrode potentials given in volts. The size and sign of the electrode potential indicates how easily these elements will take on or give up electrons or corrode. Hydrogen is arbitrarily assigned a value of zero.*

To investigate the influence of the size of the exposed area, withdraw the copper electrode until exactly half the surface area of the electrode is removed from the water. The current will drop to exactly half of what it was with the entire area of the electrode submerged. If, on the other hand, half of the iron electrode is removed, the current will be somewhat less, but still well above half of its original value. Since the area of exposed iron is only half as much as before, and the corrosion rate on each square inch is still more than half the original rate, the corrosive attack on the metal has been intensified.

This experiment illustrates a very important corrosion principle known as the "Catchment Area" principle. This principle states that the galvanic current increases with increasing *CATHODIC* area, just as the water yield from a watershed increases as the area increases.

Let's study this principle. We have decided to protect the steel anode with a coat of paint. As long as the paint is perfect, there will be no corrosion. However, if there are any "pinholes" in the coating of paint, corrosive attack at these points will be much greater than it would have been with no paint coating at all. On the other hand, if the steel anode is protected by painting the copper cathode (thus reducing the cathodic area), the corrosion rate will be zero with a perfect coating, and it will still be very small even if the coating contains pinholes.

In the same way, *CORRISION INHIBITORS*[27] that slow the cathodic reaction (in this example, the reaction on the copper electrode) are known as "safe" inhibitors. Inhibitors that act on the anode reaction are called "dangerous" inhibitors because if there is not quite enough inhibitor added, severe pitting will result and corrosion will be worse than if none had been added.

In the ordinary large gate valve used in water distribution systems, brass or bronze parts often make contact with the valve's cast iron body. The brass or bronze and cast iron create a galvanic cell, but the area of the brass or bronze is so small, compared to the area of the cast iron, that galvanic corrosion is negligible.

We encounter many similar situations in the water works field. For example, copper in a valve can be the cathode and the steel or cast iron in the valve the anode. As long as the cathode area is small relative to the anode, corrosion will not be a problem. However, if a copper service line is connected to a steel main, the cathode area is large relative to the anode and corrosion will occur at the anode. The opposite will occur with a brass valve in a steel water line. The cathode area is small and the anode area is large so there will be no problem.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 369.

8.1D Why does the current drop significantly in an experimental galvanic cell a few minutes after the switch is first closed?

8.1E What is the "dezincification" of brass?

8.1F How does dissolved oxygen in water influence the corrosion rate?

8.1G What is a "dangerous" corrosion inhibitor?

8.1H What will happen if a copper service line is connected to a steel water main?

8.112 Salinity

What is the impact of salinity (conductivity) on corrosion? First, let's return our experimental galvanic cell in Figure 8.4 to its original position. Next turn on the stirrer and add a pinch of salt. Quite simply, salt increases the electrical conductivity of the water, so the corrosion current increases.

8.113 Cathode Film Formation

In another experiment with our galvanic cell, add a pinch of powdered calcium carbonate ($CaCO_3$ or limestone). After a while, the current will become so small that it cannot be measured. Also, the copper cathode will become coated with a very thin film of calcium carbonate ($CaCO_3$). This illustrates a very important principle in water treatment. *A THIN FILM OR COATING OF CALCIUM CARBONATE CAN DRASTICALLY INHIBIT CORROSION.*

If you stir the water in the presence of a powdered calcium carbonate, the solution (water) will become saturated with calcium carbonate. Some of the calcium carbonate reacts with carbon dioxide from the air as follows:

$$\begin{array}{c}\text{Calcium}\\\text{Carbonate}\end{array} + \begin{array}{c}\text{Carbon}\\\text{Dioxide}\end{array} + \text{Water} \rightarrow \text{Calcium} + \text{Bicarbonate}$$

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2\,HCO_3^-.$$

This means that calcium carbonate, carbon dioxide, and water react to form calcium ions and bicarbonate ions in solution.

Then when the cathode reaction occurs in a solution saturated with calcium carbonate and containing calcium ions and bicarbonate ions, the following reaction takes place:

$$\begin{array}{c}\text{Calcium}\\\text{Ion}\end{array} + \begin{array}{c}\text{Bicarbonate}\\\text{Ion}\end{array} + \begin{array}{c}\text{Hydroxide}\\\text{Ion}\end{array} \rightarrow \begin{array}{c}\text{Calcium}\\\text{Carbonate}\end{array} + \text{Water}$$

$$Ca^{2+} + HCO_3^- + OH^- \rightarrow CaCO_3 + H_2O.$$

This means that calcium ions, bicarbonate ions and hydroxide (hydroxyl) ions react to form calcium carbonate and water. The hydroxyl ions are formed by the reduction of oxygen on the cathode. The calcium carbonate (limestone) film on the cathode slows the flow of dissolved oxygen to the cathode so much that the corrosion reaction is for all practical purposes *STOPPED.*

---

[27] *Corrosion Inhibitors. Substances that slow the rate of corrosion.*

In order for this film to form, the following four conditions must be met.

1. The water must be saturated with calcium carbonate. If the water were undersaturated, whatever calcium carbonate formed would dissolve.
2. The water must contain bicarbonate ions because no direct chemical reaction occurs between hydroxyl and carbonate ions.
3. The pH cannot be too high for two reasons. As the pH *INCREASES*, the portion of the alkalinity in the water in the form of bicarbonate ions *DECREASES*. Also, if the pH is high, there is so much hydroxyl ion present that the additional hydroxyl ions from the cathode reaction have little effect. Therefore, pH values should never exceed 9.4 and should preferably be below 8.7.
4. There must be movement in the water that is next to the cathode. Otherwise, the calcium and bicarbonate ions near the cathode will be used up quickly and the calcium carbonate will be formed so far from the cathode that the calcium carbonate will not form a protective film.

8.114 Water Velocities

While normal water velocities (less than 5 ft/sec or 1.5 m/sec) are beneficial, excessive velocities may cause a form of corrosion known as "erosion corrosion." Copper tubing is particularly susceptible and velocities of over five ft/sec (1.5 m/sec) should be avoided. For additional information on the control of corrosion in distribution systems, see *WATER SUPPLY SYSTEM OPERATION*, Chapter 7, "Distribution System Operation and Maintenance."

8.115 Zinc Coatings

One of the most common galvanic cells is the zinc-iron cell. When zinc is made to be the anode, the iron cathode does not corrode. To take advantage of this fact we protect the iron with a thin coating of zinc in a process called galvanization. This product is called galvanized iron.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 369.

8.1I What is the impact (effect) of salinity on corrosion?

8.1J What is the impact of calcium carbonate on corrosion?

8.1K What causes "erosion corrosion" in copper tubing?

8.12 Oxygen Concentration Cell

Although galvanic cells are responsible for some corrosion problems, by far the most common corrosion cell is the oxygen concentration cell. In order to understand an oxygen concentration cell, think in terms of the *DEAD END*[28] created by a six-inch (150 mm) dry barrel fire hydrant installed on an eight-inch (200 mm) water main (Figure 8.5). The fire hydrant assembly will normally consist of an 8" x 8" x 6" (200 mm x 200 mm x 150 mm) tee, six-inch (150 mm) nipple, a six-inch (150 mm) gate valve, 10 to 20 feet (3 to 6 m) of six-inch (150 mm) pipe and the fire hydrant. When corrosion starts in the six-inch (150 mm) pipe, the following chemical reaction occurs:

$$\text{Iron} \rightarrow \text{Ferrous Ion} + \text{Electrons}$$
$$Fe \rightarrow Fe^{2+} + 2\,e^{-}.$$

This is the anode reaction of the galvanic cell. The ferrous ions (Fe^{2+}) formed by this reaction will in turn react with dissolved oxygen and water as follows:

$$\underset{\text{Ions}}{\text{Ferrous}} + \underset{\text{Oxygen}}{\text{Dissolved}} + \text{Water} \rightarrow \underset{\text{(Solid)}}{\text{Ferric Hydroxide}} + \underset{\text{Ions}}{\text{Hydrogen}}$$
$$4\,Fe^{2+} + O_2 + 10\,H_2O \rightarrow Fe(OH)_3\downarrow + 8\,H^{+}.$$

This is chemical shorthand for saying that four ferrous ions and one molecule of oxygen react with ten water molecules to form four molecules of solid (precipitate) ferric hydroxide and eight hydrogen ions.

Just as they did in the galvanic cell, the electrons from the anode reaction flow through the metallic path (pipe) to the eight-inch (200 mm) main where they react with dissolved oxygen which is continually being replenished by the flowing water.

$$\text{Oxygen} + \text{Electrons} + \text{Water} \rightarrow \text{Hydroxide Ions}$$
$$O_2 + 4\,e^{-} + 2\,H_2O \rightarrow 4\,OH^{-}$$

This is the cathode reaction.

The continued production of ferrous ions within the six-inch (150 mm) pipe, completely removes dissolved oxygen from the water in the dead end and also scavenges any dissolved oxygen that may diffuse in from the flowing water in the eight-inch (200 mm) pipe. The hydrogen ions produced by this reaction can lower the pH in the water down to around 5.2 to 5.8.

Also, the production of positively charged ferrous ions in the six-inch (150 mm) pipe, requires that there be an inflow of negatively charged ions to maintain electrical neutrality in the water. The common negative ions present in water are bicarbonate (HCO_3^-), chloride (Cl^-), and sulfate (SO_4^{2-}).

The absence of oxygen and the low pH value in the six-inch (150 mm) pipe make conditions ideal for the growth of *ANAEROBIC*[29] bacteria. The action of these bacteria on traces of organic matter and on reducing the sulfate ions to sulfide are responsible for the foul odors usually found in the dead ends of water mains.

The typical distribution system contains many dead ends. In addition to those at the end of the system, other dead end conditions include the *ANNULAR SPACES*[30] (circular cavities) created by mechanical couplings, tapping sleeves (Figure 8.6), and even the bonnets (covers) of gate valves, but the number of dead ends from pits (holes) in the pipe surfaces far exceeds the number of dead ends from all other causes combined.

Pits may be started by anything that will shield the metal surface from dissolved oxygen in the water, such as bits of clay, dirt, sand or a colony of bacteria. Also impurities in the metal may cause a local anode to form.

---

[28] *Dead End. The end of a water main which is not connected to other parts of the distribution system by means of a connecting loop or pipe.*

[29] *Anaerobic (AN-air-O-bick). A condition in which "free" (atmospheric) or dissolved oxygen is NOT present in water.*

[30] *Annular Space (AN-you-ler). A ring-shaped space located between two circular objects, such as two pipes.*

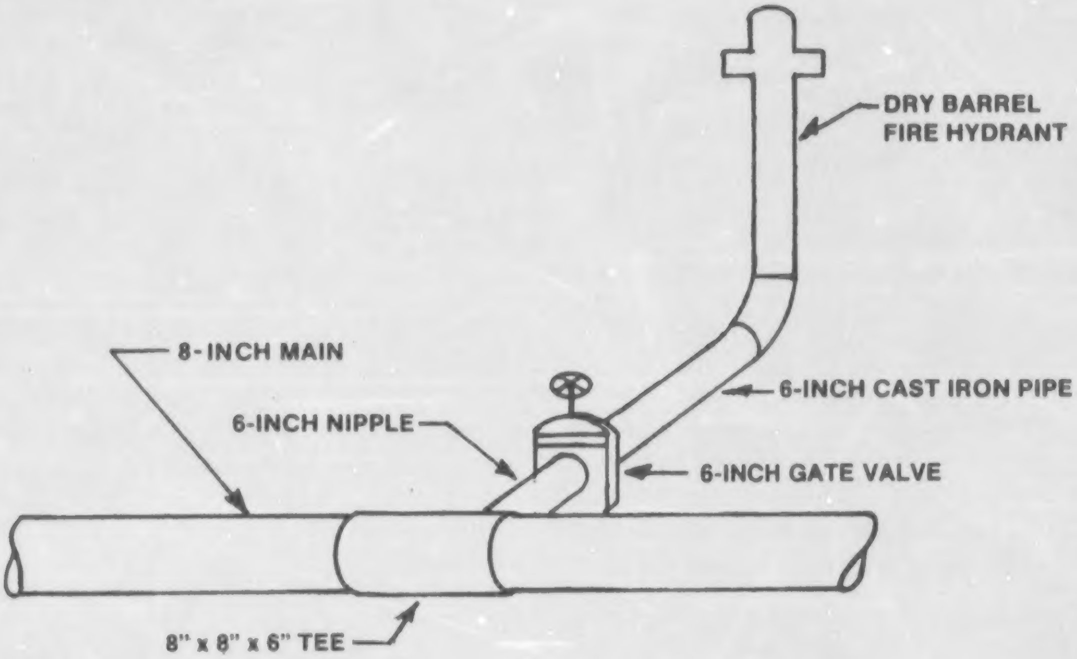

DRY BARREL
FIRE HYDRANT
8-INCH MAIN
6-INCH CAST IRON PIPE
6-INCH NIPPLE
6-INCH GATE VALVE
8" x 8" x 6" TEE

Fig. 8.5 Dead end caused by installation of fire hydrant

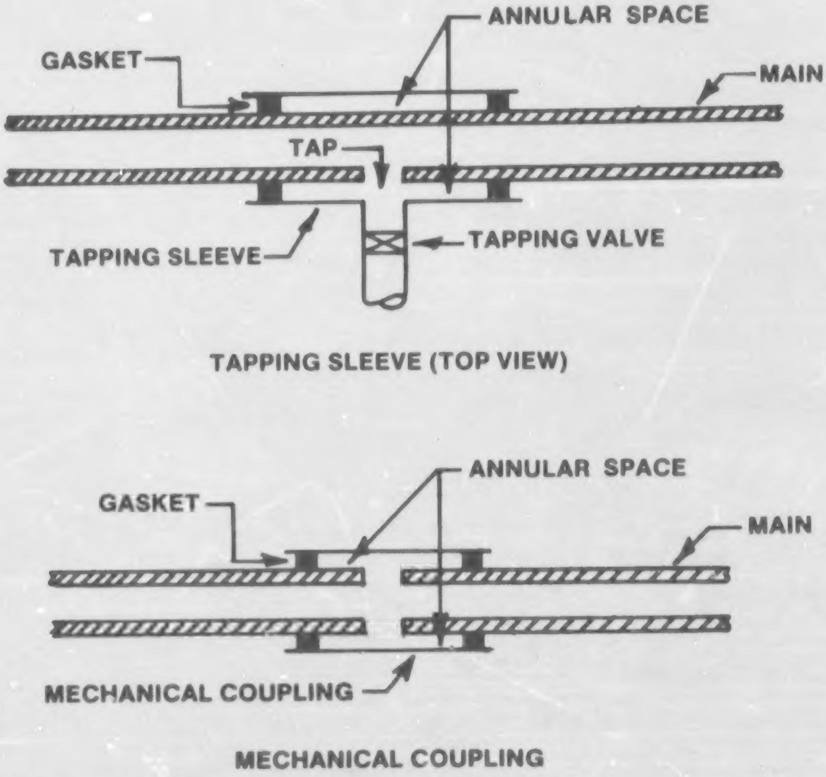

ANNULAR SPACE
GASKET
MAIN
TAP
TAPPING SLEEVE
TAPPING VALVE
TAPPING SLEEVE (TOP VIEW)
ANNULAR SPACE
GASKET
MAIN
MECHANICAL COUPLING
MECHANICAL COUPLING

Fig. 8.6 Creation of annular spaces in distribution systems

As the iron ions from the anode react with the dissolved oxygen in the water, the resulting ferric hydroxide forms a membrane over the anode. As the reactions continue and the membrane ages, it turns into a crust. The membrane, and later the crust, protect the anode area from dissolved oxygen in the water, thus causing the oxygen concentration cell to intensify itself. As the iron ions leave the metal, a pit is formed that grows deeper and deeper. As this occurs the crust becomes thicker and thicker. In this way, a mound of iron rust is built up over the pit. This mound is called a *TUBERCLE*.[31]

As the ferric hydroxide ($Fe(OH)_3$) ages, it forms other minerals (such as ferric oxide (Fe_2O_3) or iron rust). Eventually, the crust becomes so thick that negative ions cannot enter the pit, nor can iron ions escape, and the corrosion stops. At this point the pit is said to be inactive.

The reaction of dissolved oxygen with ferrous ions is very slow at low pH values. When the pH is less than seven, the reaction is so slow that tubercles do not form and the pits are not self perpetuating. New pits keep starting in different places, so that corrosion appears to be uniform over the surface of the pipe.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 369.

8.1L What is the most common type of corrosion cell?

8.1M How can an oxygen concentration cell be started?

8.1N What is a tubercle?

8.1O How can pits be started on a metallic surface under water?

End of Lesson 1 of 2 Lessons on CORROSION CONTROL

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. CORROSION CONTROL

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions which you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson.

Write the answers to these questions in your notebook before continuing.

1. What are the adverse effects caused by corrosive waters?
2. Why should aluminum never be imbedded directly in concrete?
3. What could happen to unlined steel pipes in a water distribution system if bluestone (copper sulfate) is used to control algal growths in a reservoir?
4. How does salinity influence corrosion?
5. How does calcium carbonate inhibit corrosion?
6. What conditions must be met in order for a protective calcium carbonate film to form on pipe walls?

---

[31] *Tubercle (TOO-burr-cull). A protective crust of corrosion products (rust) which builds up over a pit caused by the loss of metal due to corrosion.*

Chapter 8. CORROSION CONTROL

(Lesson 2 of 2 Lessons)

8.2 HOW TO DETERMINE IF CORROSION PROBLEMS EXIST

The Safe Drinking Water Act prohibits water systems from serving corrosive water because of the possibility of corroding lead or other toxic metals into the water. However, the Act does not completely define corrosive water. Therefore, the water utility may be expected to prove that the water is not corrosive. See Section 8.315, "Corrosivity by INDICES,[32]" for measures of corrosive characteristics of water.

To determine if the water you are treating is causing corrosion problems, you can examine materials removed from your distribution system for signs of corrosion damage. Chemical tests on the water can be used to indicate the corrosiveness of a water. *IF THE DISTRIBUTION SYSTEM HAS AN INCREASING NUMBER OF LEAKS AND THE CONSUMERS ARE COMPLAINING ABOUT DIRTY OR RED WATER, THESE ARE THE MOST COMMON INDICATORS OF CORROSION PROBLEMS.*

8.20 Examine Materials Removed From Distribution System

Corrosion rates may be measured by inserting special steel specimens called "coupons" in the water mains. After a period of time, usually a month or two, the coupons are removed and the loss of weight and nature of corrosion damage is measured. These tests should be made under the supervision of an experienced corrosion engineer because standard procedures must be used to obtain results that can be compared with other water supply systems.

8.21 Leaks and Depth of Pits

Much can be learned about the corrosiveness of a water by prowling through the scrap heap and examining sections of water mains that have been taken out of service for various reasons. When examining internal corrosion damage on a pipe, pay particular attention to the maximum depth of the pits. When pit depth equals the wall thickness of a pipe, a leak develops. As a rule of thumb, you can assume (for internal corrosion only) that pit depth increases with the cube root of time ($\sqrt[3]{\text{Time}}$). Thus, if a pit depth reaches a certain value in one year, it will about double this depth in eight years (2 × 2 × 2 = 8).

Leaks are often detected by the observation of wet spots above a pipeline. All reports of leaks should be recorded. If the number of leaks is large, plot the location of the leaks on a map to identify trouble spots.

If effervescence (bubbles) occurs when a drop of dilute hydrochloric (HCl) acid is placed on an obvious cathodic area (such as a brass ring on a gate valve), this indicates the presence of a calcium carbonate ($CaCO_3$) film that may be too thin to see. This indicates that the water is, at worst, only moderately corrosive.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 369.

8.2A Why should water systems be prohibited from serving corrosive water?

8.2B How can corrosion rates be measured?

8.2C How can leaks in water mains be detected?

8.2D How can you detect a film of calcium carbonate that is too thin to see?

8.22 Flow Tests

A very simple and useful *CORROSIVITY*[33] test is to measure the change in water flow through a 20-foot (6-meter) length of half-inch (12.5 mm) standard black iron pipe under a constant head of one foot (0.3 m). The initial flow rate will be small enough that the flow rate can be determined by measuring the time required to fill a one quart (or one liter) container. If the water is highly corrosive, the flow rate will be reduced by as much as 50 percent in two weeks. In other words, the fill time will be twice as long. If the water is relatively non-corrosive, the flow reduction will be only 10 percent or less after two weeks. This test may be run for longer time periods, but the changes in flow caused by tuberculation are greatest during the first few weeks. Usually there is little change after 26 weeks.

8.23 Chemical Tests On The Water

8.230 Dissolved Oxygen

Certain chemical tests on the water may be helpful to indicate the corrosiveness of a water. As you've learned, corrosion can only occur in the presence of oxygen. Water supplies taken from lakes or streams will contain dissolved oxygen. If your source water is drawn from wells, measure the dissolved oxygen[34] concentration in each well. If no oxygen is present, the water cannot be corrosive.

By measuring the dissolved oxygen at various points in the distribution system, you can calculate how much oxygen is used up as water passes through the system. Loss of dissolved oxygen indicates either that the water contains oxidizable organic matter or that gross corrosion is occurring.

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[32] *Indices is the plural form of index and is pronounced IN-duh-sees.*

[33] *Corrosivity. An indication of the corrosiveness of a water. The corrosiveness of a water is described by the water's pH, alkalinity, hardness, temperature, total dissolved solids, and the Langelier Index (See Section 8.311, "Langelier Index").*

[34] *Refer to Chapter 11, "Laboratory Procedures," and Chapter 21, "Advanced Laboratory Procedures," in this manual.*

When taking samples for dissolved oxygen, you must avoid exposing the sample to air because air contains oxygen. You will need the following equipment and reagents:

1. A four-foot (1.2 m) length of polyethylene tubing with fittings to connect to a hose bib (faucet).
2. BOD bottle. A glass bottle with 300 m*L* capacity with a tapered, pointed, ground-glass stopper with a flared mouth.
3. Three small (100 m*L*) plastic bottles with screw on rubber bulb dispensing pipets. These pipets should deliver approximately 0.5*L* when the bulb is squeezed (an ordinary eye dropper is satisfactory). The bottles are filled with standard reagents available from chemical supply houses.
   a. Manganous sulfate.
   b. Alkaline potassium iodide.
   c. Concentrated sulfuric acid. This is a very dangerous chemical and must be handled with great care.

To obtain a *REPRESENTATIVE SAMPLE*,[35] select a hose bib as close as possible to the meter of a customer on a short water service. Flush the service line at a rate of approximately half a gallon per minute (2 *L*/min) for five minutes for each 100 feet (30 m) of pipe between the hose bib and the main so that you can be sure you are getting your sample from the main. Do not flush the service line at a high water velocity because this may disturb sediment in the pipe. Therefore, take a long time to flush the line out. After the line has been flushed, connect the plastic tube to the hose bib, place the end of the plastic tube at the bottom of the BOD bottle, and turn the hose bib on again at a rate of flow no higher than was used for flushing the service line. Allow the flow to continue until the BOD bottle has overflowed at least three times its volume. Withdraw the plastic tube taking care not to introduce any air bubbles while removing the tube.

Next, "fix" (stop any chemical reactions involving dissolved oxygen) the sample so it can be transmitted to the laboratory where the dissolved oxygen can be measured.

1. Gently, but rapidly, add one m*L* of manganese sulfate reagent (two squirts with dropper) followed by one m*L* of alkaline potassium iodide. Each time hold the tip of the pipet below the surface of the water so you will not add any dissolved oxygen.

   A heavy brown floc of manganese hydroxide will form at this point if there is dissolved oxygen present. A white floc will indicate that there is no dissolved oxygen in the water.
2. Insert the glass stopper without trapping any air bubbles. Mix sample and reagents by rapidly inverting the bottle back and forth.
3. Allow the floc to settle halfway down in the bottle. Shake the bottle by inverting and allow the floc to settle halfway again.
4. Carefully remove the stopper and add one m*L* of concentrated sulfuric acid. Allow the acid to run down the neck of the bottle and into the sample.
5. Mix the sample by inverting again.

The sample now contains an iodine solution that is chemically equivalent to the initial dissolved oxygen concentration in the sample. The final solution is stable and can be transported to the laboratory where the iodine solution can be measured by *TITRATING*[36] with a standard solution of sodium thiosulfate. See Chapter 11, "Laboratory Procedures," for details.

8.231 Toxic Heavy Metals

Testing for toxic heavy metals in water samples from customers' plumbing has been recommended as a way of determining whether the delivered water is corrosive. However, the results of such samples are so variable that a great many samples must be taken in order to obtain a meaningful average.

A common source of lead from plumbing is copper tubing with soldered fittings. A water sample taken shortly after a period of heavy use will contain much less lead than a sample taken after standing overnight. Experiments have shown that on new copper tube systems, significant amounts of lead are found in water samples regardless of the water quality. With non-corrosive water, no lead can be detected from copper plumbing one month old, and even with moderately corrosive water, lead is low after approximately two years. With highly corrosive water, excessive lead concentrations may be found after more than ten years.

Cadmium is the only other toxic metal found in samples from plumbing systems and it is found only in very small amounts. Cadmium is a contaminant found in zinc used for galvanizing steel pipes. Cadmium-plated waterworks fittings are not used in the United States. However, they have been used in Europe and have been responsible for serious cases of cadmium poisoning.

Chromium is used for external decorative plating and has virtually no chance to get into the water. Arsenic, antimony and silver are found in copper and zinc ores, but the quantities found in the refined metals used for plumbing are too small to be significant sources of contamination of drinking water.

8.24 Marble Test[37]

The marble test for calcium carbonate *SATURATION*[38] is a very useful test. First, measure the pH, alkalinity and hardness of the water sample. Add a pinch of powdered calcium carbonate and then stir the water for five minutes. If the pH, alkalinity, or calcium have increased, the water was undersaturated; if they decrease, the water was *SUPERSATURATED*[39] with respect to calcium carbonate.

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[35] *Representative Sample. A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.*

[36] *Titrate (TIE-trate). To TITRATE a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction as signaled by the end point.*

[37] *Marble Test. See Chapter 21, "Advanced Laboratory Procedures," for detailed procedures on how to perform the Marble Test.*

[38] *Saturation. The condition of a liquid (water) when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.*

[39] *Supersaturated. An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.*

The water should be stirred in a stoppered flask on a magnetic stirrer in order to avoid the introduction of carbon dioxide from the air. Also, the water being stirred should be at the same temperature as the water in the distribution system. If the marble test is made frequently, it is convenient to use an Enslow column. This is a column packed with calcium carbonate granules. The pH, alkalinity and calcium are measured on a sample stream of water before and after passing through the column. See Section 8.34, "Determination of Chemical Feeder Setting," for a detailed description of an Enslow column.

Results from either the Marble Test or an Enslow column may be as follows:

Initial pH = 8.7 Initial Hardness = 34 mg/*L* as $CaCO_3$

Final pH = 9.1 Final Hardness = 38 mg/*L* as $CaCO_3$

The tested water is considered corrosive because the pH and hardness both increased in the test. An increase in these values indicates that the water was undersaturated with calcium carbonate to begin with.

8.25 Complaints

Accurate records should be maintained of all complaints, and if more than a minimum number of rusty or red water complaints are received, they should be plotted on a map of the system. The distribution of the plots can tell you where corrosion problems are occurring and indicate how the problem can be corrected. See the section on "Handling Water Quality Complaints" in Chapter 10, "Plant Operation," for more details.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 370.

8.2E What does a loss of dissolved oxygen in the water flowing in a distribution system indicate?

8.2F What toxic metals may enter drinking waters from the customer's plumbing due to corrosive water?

8.2G How can water be tested to determine if it is undersaturated or supersaturated with calcium carbonate?

8.2H What do rusty or red water complaints indicate?

8.3 METHODS OF CONTROLLING CORROSION

8.30 Calcium Carbonate Saturation

If the water is corrosive, treatment to reduce the corrosivity of the water should be undertaken. Reduction of corrosivity is almost always accomplished by treating the water with chemicals (Figure 8.7) so that the water is saturated or slightly supersaturated with calcium carbonate. Chemicals should be fed *AFTER* filtration; otherwise a slight excess chemical may result in cementing of filter sands. (Samples for turbidity measurements should be taken after filtration but before chemical feed. Small amounts of turbidity could be introduced with the chemical and might produce misleading results suggesting poor filter performance.) The chemical feed can take place before, after, or along with postchlorination. However, samples should be taken only after postchlorination because the chlorine may react with the chemicals used to reduce corrosivity. For example, chlorine gas will lower the pH of the water, while hypochlorite compounds will raise the pH.

Selection of a chemical to achieve calcium carbonate saturation will depend on the water quality characteristics of the water and the cost of chemicals. Quicklime and hydrated lime should be added to waters which have a low hardness and low alkalinity in order to form calcium carbonate. Caustic soda or soda ash may be added to waters with high levels of hardness and alkalinity because there is already sufficient calcium alkalinity to form calcium carbonate, but the pH must be increased to reach saturation conditions.

Quicklime is calcium oxide (CaO) and is the least expensive of the four chemicals. However, lime requires expensive equipment to *"SLAKE"*[40] or hydrate it. This procedure is cost effective only for very large water treatment plants.

Hydrated lime is calcium hydroxide ($Ca(OH)_2$) and is slightly more costly than unslaked lime. Hydrated lime is only slightly soluble in water so it cannot be fed as a true solution. Lime *SLURRY*[41] reacts with carbon dioxide to form limestone (calcium carbonate or $CaCO_3$) so pipes, pumps, and solution feeders tend to become plugged with scale or deposits very rapidly. For this reason, hydrated lime is best fed using a dry feeder. Use of either form of lime will add hardness to the water. This extra hardness may be a slight disadvantage where the water already contains too much calcium or hardness. However, the lime is advantageous for waters that contain so little calcium that they cannot otherwise be saturated with calcium carbonate.

Lime should be fed to the water after it has passed through the filters, but before it enters the clear well. Provisions should be made to collect turbidity samples or measure turbidity between the filters and the location of the lime feed because lime will cause an increase in the turbidity of the filtered water.

Lime can be very difficult to handle. If you are having problems with calcium carbonate forming in the pipes which are delivering lime to the point of application, consider the construction of open channels so the deposits of lime can be cleaned from the channel with a hoe. Other possibilities include the use of flexible pipelines (rather than rigid pipe) such as plastic hose for ease in breaking the calcium carbonate deposits loose. The outlet of any pipe or hose should not be submerged. To reduce the problem of cleaning either pipes or open channels, minimize the length of the solution lines by placing the chemical feeder as close as possible to the point of application.

Caustic soda (NaOH or sodium hydroxide) is more expensive than lime, but is available in a 50 percent solution that can be fed directly with less expensive solution feeders. There are some waters, however, with initial calcium and alkalinity levels so low that calcium cabonate ($CaCO_3$) saturation cannot be reached by feeding caustic soda. When considering the use of cautic soda, problems associated with the feeding of caustic soda must be considered. Caustic soda crystallization (freezing) occurring at temperatures below around 50°F (10°C) can be a problem. At locations where caustic soda is fed to the water being treated, the caustic should not be fed in a closed conduit or pipe because this will encourage clogging.

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[40] *Slake. To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.*

[41] *Slurry (SLUR-e). A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).*

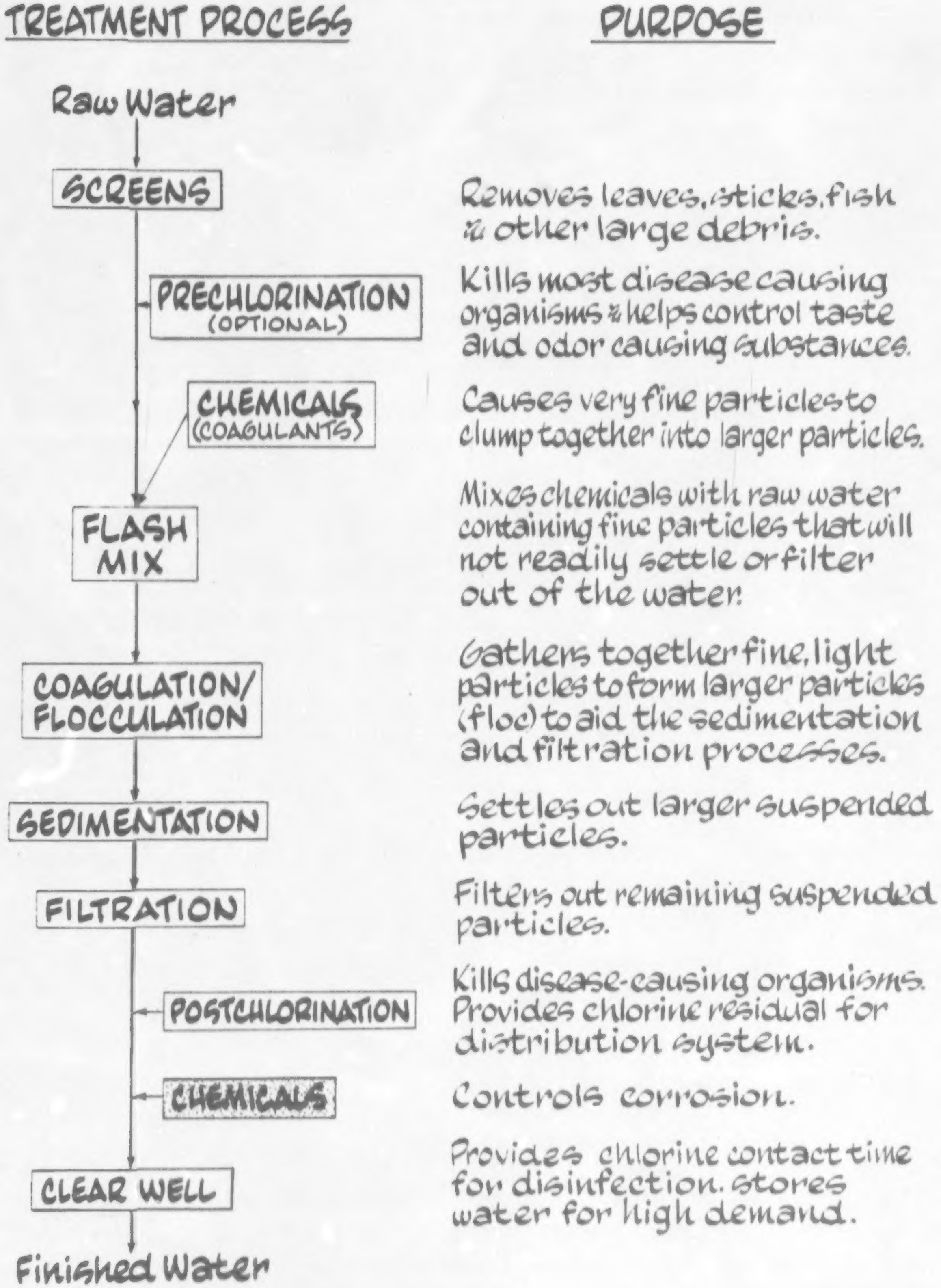
TREATMENT PROCESS
PURPOSE
Raw Water
SCREENS
Removes leaves, sticks, fish & other large debris.
PRECHLORINATION (OPTIONAL)
Kills most disease causing organisms & helps control taste and odor causing substances.
CHEMICALS (COAGULANTS)
Causes very fine particles to clump together into larger particles.
FLASH MIX
Mixes chemicals with raw water containing fine particles that will not readily settle or filter out of the water.
COAGULATION/ FLOCCULATION
Gathers together fine, light particles to form larger particles (floc) to aid the sedimentation and filtration processes.
SEDIMENTATION
Settles out larger suspended particles.
FILTRATION
Filters out remaining suspended particles.
POSTCHLORINATION
Kills disease-causing organisms. Provides chlorine residual for distribution system.
CHEMICALS
Controls corrosion.
CLEAR WELL
Provides chlorine contact time for disinfection. Stores water for high demand.
Finished Water

Fig. 8.7 Typical process flow diagram

Caustic soda must be handled with great care because caustic soda (1) dissolves human skin, (2) when mixed with water causes heat, and (3) reacts with amphoteric metals (such as aluminum) generating hydrogen gas which is flammable and may explode if ignited. When handling caustic soda you should control the mists with good ventilation. You must protect your nose and throat with an approved respiratory system. For eye protection you must wear chemical worker's goggles and/or a full face shield to protect your eyes. You should protect your body by being fully clothed, and by using impervious gloves, boots, apron and face shield.

Soda ash is sodium carbonate (Na_2CO_3). Sodium carbonate will dissolve in water up to approximately 1⅓ pounds per gallon (0.16 kg/*L*) and can thus be fed with solution feeders. Soda ash can be used in waters of low alkalinity (where caustic cannot) provided the calcium hardness is greater than about 30 mg/*L* (as $CaCO_3$). Since such waters are rare, it is not a common method of treatment. When comparing the applications of soda ash and caustic soda, consider the cost of increasing the alkalinity by one mg/*L*. This will require consideration of the cost per pound of chemical, the percent purity of the chemical, and the change in alkalinity or pH resulting from the application of the chemical.

Utilities should exercise caution when applying compounds containing sodium. Use of corrosion control chemicals containing sodium should be carefully reviewed where the added sodium will increase the level in the water to more than 20 mg/*L*. Public health officials are concerned because evidence indicates that sodium is one important factor in the development of high blood pressure in susceptible individuals.

Finding the chemical dosage required to change the pH and produce saturation of a given water with calcium carbonate is not simple. Before discussing how to calculate the dosage, we will discuss the various indices of calcium carbonate saturation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 370.

8.3A How can the corrosivity of a water be reduced?

8.3B What chemicals may be added to waters to reduce the corrosivity?

8.31 Indices of Calcium Carbonate Saturation

A water is considered stable when it is just saturated with calcium carbonate. In this condition the water will neither dissolve nor deposit calcium carbonate. Thus, in this water the calcium carbonate is in equilibrium with the hydrogen-ion concentration. If the pH is raised from the equilibrium point (pH_s), the water becomes scale forming and will deposit calcium carbonate. If the pH is lowered from the equilibrium point, the water turns corrosive. This section will discuss the various indices used to determine how close a water is to the equilibrium point, or the corrosiveness of the water.

8.310 Driving Force Index (D.F.I.)

The easiest to understand of the several corrosion indices is called the Driving Force Index (D.F.I.). If the Driving Force Index is less than one, the water is considered corrosive and if it is greater than one the water is *SUPERSATURATED* with respect to calcium carbonate (noncorrosive). If the Driving Force Index is one, the water is considered stable or in equilibrium with respect to calcium carbonate.

The Driving Force Index (D.F.I.) is defined by equation (1).

$$\text{D.F.I.} = \frac{[Ca^{2+}][CO_3^{\,2-}]}{K'_{sp} \times 10^{10}} \tag{1}$$

In this equation $[Ca^{2+}]$ is the calcium hardness in mg/*L* as $CaCO_3$; $[CO_3^{\,2-}]$ is the carbonate alkalinity in mg/*L* as $CaCO_3$; and K'_{sp} is called the solubility product for calcium carbonate. K'_{sp} is a constant for any given water although its value varies with temperature and a measure of mineralization called the ionic strength. See Table 8.2. Carbonate alkalinity may be found from the alkalinity and pH using the nomograph on page 266 of the Fifteenth Edition of *STANDARD METHODS*.[42]

Figure 8.8 is a plot of D.F.I. vs. *pH*.[43] The pH_s is the pH level at which the water is just saturated with calcium carbonate. Since this occurs when D.F.I. = 1, Figure 8.8 shows that there are two values of pHs for the more mineralized (more dissolved salts) waters and no pH_s value for waters that are only slightly mineralized. Note that most waters have two values of pH_s and that waters with low alkalinity and calcium have no pH_s value. Also note in Figure 8.8 that *ALKY* stands for *ALKALINITY*.

EXAMPLE 1

Calculate the Driving Force Index (D.F.I.) of a water at 15°C having TDS of 200 mg/*L*, a calcium hardness of 50 mg/*L* as $CaCO_3$ and a carbonate ($CO_3^{\,2-}$) level of 3.58 mg/*L* as $CaCO_3$. The K'_{sp} value for calcium carbonate ($CaCO_3$) is 7.742×10^{-9}.

Known		Unknown
Water Temp., °C	= 15°C	D.F.I.
TDS, mg/*L*	= 200 mg/*L*	
Ca Hardness, mg/*L*	= 50 mg/*L* as $CaCO_3$	
$CO_3^{\,2-}$, mg/*L*	= 3.58 mg/*L* as $CaCO_3$	
K'_{sp} for $CaCO_3$	= 7.742×10^{-9}	

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[42] *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. Available from AWWA Data Processing Department, 6666 West Quincy Avenue, Denver, Colorado 80235. Price $40.00 to members; $50.00 for non-members.*

[43] $pH = \log\frac{1}{(H^+)}$.

TABLE 8.2 K'_{sp} VALUES FOR WATER AT VARIOUS TEMPERATURES AND TDS[a] VALUES[b]

TEMP. °C	TDS, mg/L 0	100	200	400	800	1000
0	4.457	6.839	8.035	9.977	13.213	14.689
4	4.467	6.855	8.072	10.023	13.305	14.791
8	4.416	6.808	8.017	9.977	13.243	14.757
12	4.325	6.683	7.889	9.840	13.092	14.555
16	4.198	6.501	7.691	9.594	12.794	14.256
20	4.036	6.281	7.413	9.268	12.388	13.804
25	3.802	5.929	7.015	8.790	11.749	13.122
30	3.524	5.521	6.546	8.204	11.015	12.303

[a] TDS: Total Dissolved Solids.
[b] NOTE: Mutliply all table values by 10^{-9} when using Equation (1). See EXAMPLE 1 for procedures on how to do this.

Calculate the Driving Force Index (D.F.I.)

$$\text{D.F.I.} = \frac{[\text{Ca}^{2+}][\text{CO}_3{}^{2-}]}{K'_{sp} \times 10^{10}}$$

$$= \frac{[50\text{ mg}/L][3.58\text{ mg}/L]}{(7.742 \times 10^{-9})(10^{10})^{*}}$$

$$= \frac{179.00}{77.42}$$

$$= 2.31$$

When the D.F.I. is greater than one, the water is supersaturated with calcium carbonate and tends to form scale.

8.311 Langelier Index (L.I.)

The Langelier Index is the most common index used to indicate the corrosiveness of a water. This index reflects the equilibrium pH of a water with respect to calcium and alkalinity. The Langelier Index can be determined by using equation (2).

$$\text{Langelier Index (L.I.)} = \text{pH} - \text{pH}_s \qquad (2)$$

where pH = actual pH of the water, and

pH_s = pH at which the water is just saturated with calcium carbonate.

In equation (2) pH_s is defined as the pH value where water of a given calcium content and alkalinity is just saturated with calcium carbonate (at the equilibrium point). Figure 8.8 shows that for waters of low calcium content and alkalinity there is no pH value that satisfies this definition and that for most waters there will be two values for pH_s. These difficulties can be avoided by defining pH_s as that pH where a water of given calcium and bicarbonate concentrations are just saturated with calcium carbonate.

T.E. Larson's method[44] for calculating pH_s is a satisfactory approximation when the value of pH_s is calculated using equation (3).

$$\text{pH}_s = A + B - \log(\text{Ca}^{2+}) - \log(\text{Alkalinity} \qquad (3)$$

The values for A and B are found in Tables 8.3 and 8.4; (Ca^{2+}) is the calcium hardness as CaCO_3; and (Alky) is the alkalinity as CaCO_3 (Table 8.5).

This calculation is accurate enough for practical purposes up to a pH_s value of 9.3. Above this value, errors are large.

EXAMPLE 2

Find the pH_s and Langelier Index of a water at 15°C having a TDS of 200 mg/*L*, alkalinity of 100 mg/*L* and a calcium hardness of 50 mg/*L*. The pH is 8.6.

Known

Water Temp., °C = 15°C
TDS, mg/*L* = 200 mg/*L*
Alkalinity, mg/*L* = 100 mg/*L* as CaCO_3
Ca Hardness, mg/*L* = 50 mg/*L* as CaCO_3
pH = 8.6

Unknown

pH_s
Langelier Index

1. Find the formula values from the tables.

   From Table 8.3 for a water temperature of 15°C,

   A = 2.12.

   From Table 8.4 for a TDS of 200 mg/*L*,

   B = 9.80.

   From Table 8.5 for Alky or 100 mg/*L* and Ca of 50 mg/*L*,

   $\log(\text{Ca}^{2+}) = 1.70,$

   $\log(\text{Alky}) = 2.00.$

2. Calculate pH_s.

   $$\text{pH}_s = A + B - \log(\text{Ca}^{2+}) - \log(\text{Alky})$$
   $$= 2.12 + 9.80 - 1.70 - 2.00$$
   $$= 8.22$$

3. Calculate the Langelier Index.

   $$\text{Langelier Index} = \text{pH} - \text{pH}_s$$
   $$= 8.6 - 8.22$$
   $$= 0.38$$

A positive Langelier Index (pH greater than pH_s) indicates that the water is supersaturated with calcium carbonate (CaCO_3) and will tend to form scale.

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*When we multiply this out $(7.742)(10^{-9})(10)^{10}$, we add up the exponents $(-9 + 10 = 1)$. This gives us $(7.742)(10^1)$ or $(7.742)(10) = 77.42$.

[44] *T.E. Larson and A.M. Buswell, "Calcium Carbonate Saturation Index and Alkalinity Interpretations," JOURNAL AMERICAN WATER WORKS ASSOCIATION, Volume 34, page 1667, 1942.*

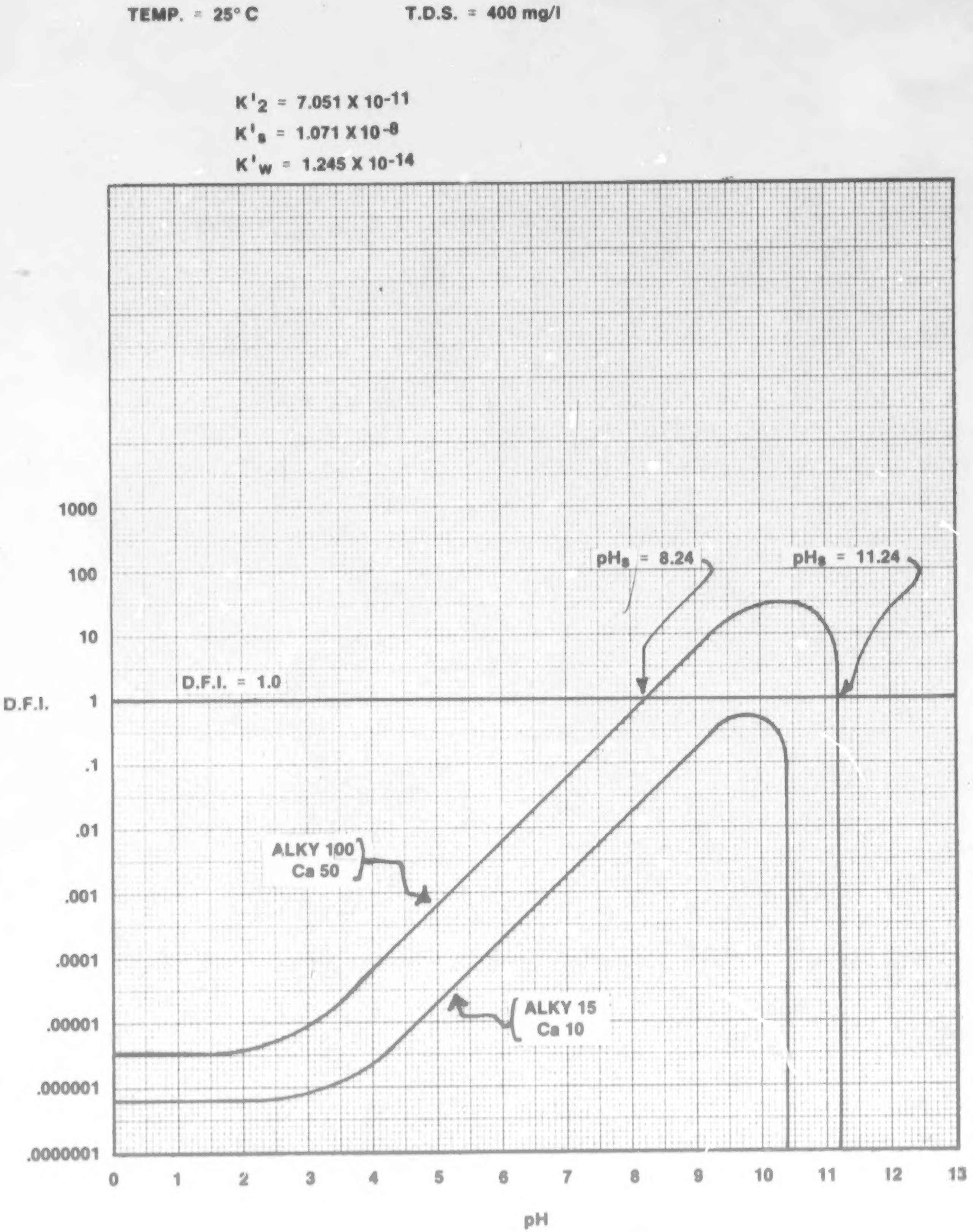


Fig. 8.8 Plot of D.F.I. vs pH

TABLE 8.3 VALUES OF A FOR VARIOUS TEMPERATURES

Temperature, °C	A
0	2.34
5	2.27
10	2.20
15	2.12
20	2.05
25	1.98
30	1.91
40	1.76
50	1.62
60	1.47
80	1.18
100	0.88

TABLE 8.4 VALUES OF B FOR VARIOUS LEVELS OF TDS

TDS, mg/*L*	B
0	9.63
50	9.72
100	9.75
200	9.80
400	9.86
800	9.94
1600	10.04

TABLE 8.5 VALUES OF LOG OF CA OR ALKY AS $CaCO_3$ IN mg/*L*

Ca or Alky as $CaCO_3$, mg/*L*	Log_{10}
10	1.00
20	1.30
30	1.48
40	1.60
50	1.70
60	1.78
70	1.84
80	1.90
100	2.00
200	2.30
300	2.48
400	2.60
500	2.70
600	2.78
700	2.84
800	2.90
900	2.95
1000	3.00

Langelier Index = $pH - pH_s$

where $pH_s = A + B - \log(Ca^{2+}) - \log(Alky)$

Soft, low alkalinity waters having excessively high pH values are corrosive even though the calculated L.I. may indicate a noncorrosive tendency. In this instance, due to the insufficient amount of calcium ions and alkalinity, no protective calcium carbonate film can form.

The corrosive tendencies of water to particular metals, such as the ones used in distribution systems, are also significantly influenced by the amount of total dissolved solids (TDS). Waters containing TDS exceeding 50 mg/*L* may exhibit corrosive tendencies in spite of a positive Langelier Index. The presence of various ions such as sulfate and chloride ions in water may interfere with the formation and maintenance of a uniform protective calcium carbonate layer on metal surfaces. In addition, the presence of these ions will accelerate the corrosion process.

Because of the various water quality indicators involved, the L.I. should only be used to determine the corrosive tendencies of water within a pH range of 6.5 to 9.5 provided that a sufficient amount of calcium ions and alkalinity over 40 mg/*L* are present in the water.

8.312 Relationship Between D.F.I. and L.I.

The relationship between the Driving Force Index and the Langelier Index can be described mathematically by

$$D.F.I. = 10^{L.I.} \qquad (4)$$

This relationship is fairly accurate for a range of the Langelier Index values from −5 to +1. This can be illustrated by referring to Figure 8.8 and drawing a 45-degree line through the pH_s value of 8.24. The resulting line will follow the line already drawn on Figure 8.8 from L.I. values of −5 to +1. Table 8.6 contains the equivalent values between D.F.I. and L.I.

EXAMPLE 3

Calculate the Driving Force Index (D.F.I.) for a water when the Langelier Index (L.I.) is 0.38.

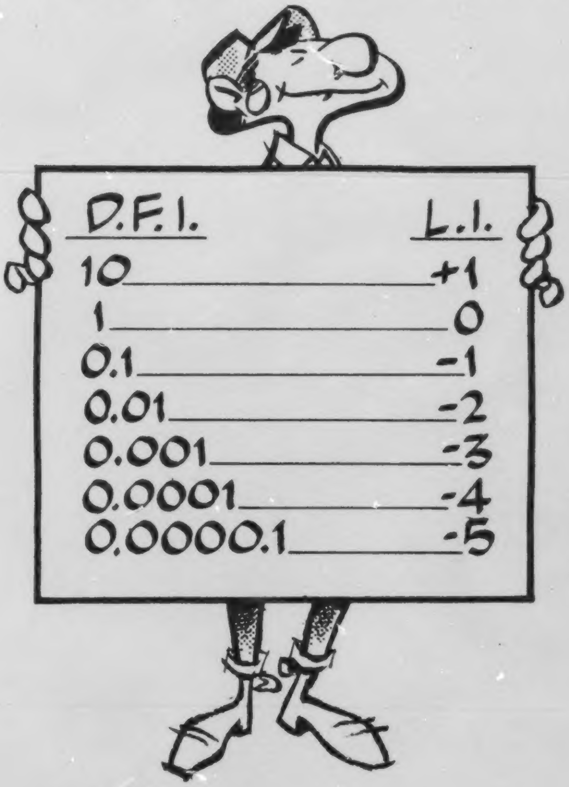
Known	**Unknown**
L.I. = 0.38	D.F.I.

Calculate the Driving Force Index from the Langelier Index.

$$\begin{aligned} D.F.I. &= 10^{L.I.} \\ &= 10^{0.38} \\ &= 2.40 \end{aligned}$$

This answer is fairly close to the 2.31 value we obtained in EXAMPLE 1.

TABLE 8.6
EQUIVALENT VALUES BETWEEN D.F.I. AND L.I.



D.F.I.	L.I.
10	+1
1	0
0.1	-1
0.01	-2
0.001	-3
0.0001	-4
0.0000.1	-5

8.313 *Ryznar Index (R.I.)*

Two other indices for calcium carbonate saturation have been proposed, the Ryznar Index and the Aggressive Index. The Ryznar Index, which is equal to 2 pH_s − pH, usually has values below 7 for highly supersaturated waters and usually has values above 7 for highly undersaturated waters, but is worthless as an index if the water is nearly saturated. This index is exact only for waters having a pH_s value of 7.00.

8.314 *Aggressive Index (A.I.)*

The Aggressive Index is equal to the pH + log(Ca^{2+}) + log(Alky) where both calcium and alkalinity are expressed in mg/*L* as $CaCO_3$,

$$A.I. = pH + \log(Ca^{2+}) + \log(Alky).$$

Water is supposed to be supersaturated if its A.I. value exceeds 12. For many waters, the value of twelve less the Aggressive Index approximates the Langelier Index, but the approximation is so rough that the number has little value.

8.315 *Corrosivity by Indices*

Table 8.7 summarizes the corrosivity characteristics associated with the Langelier, Aggressive and Driving Force Indices.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 370.

8.3C What is the meaning of a Driving Force Index (D.F.I.) of less than one?

8.3D What is the meaning of pH_s?

8.3E Why do some waters not have a meaningful pH_s value?

8.3F The Langelier Index is defined by what equation?

8.3G Find the pH_s of a water at 10°C having a TDS of 100 mg/*L*, alkalinity of 80 mg/*L* as $CaCO_3$ and a calcium hardness of 40 mg/*L* as $CaCO_3$.

8.32 Selection of Corrosion-Control Chemicals

Once you have analyzed your water and determined that you have a potential corrosion problem, the next step is to select the appropriate chemical or chemicals. Selection of chemicals depends on the characteristics of the water, where the chemicals can be applied, how they can be applied and mixed with the water, and the costs of the chemicals. You want to solve your corrosion problem by the most cost-effective means.

If, when you multiply the calcium hardness by the alkalinity (both in mg/*L* as $CaCO_3$) and the product is less than 100, then the treatment required may be complicated. For example, both lime and carbon dioxide may be required. A qualified expert's advice is desirable to determine the proper chemical doses.

If the calcium hardness times (multiplied by) the alkalinity is between 100 and 500, either lime or soda ash (Na_2CO_3) will be satisfactory. The decision regarding which chemical to use will depend on the cost of equipment and the cost of chemicals.

If the calcium hardness times the alkalinity is greater than 500, either lime or caustic (NaOH) may be used. Soda ash will be ruled out because of expense.

8.33 Determination of Chemical Dose

The chemical dose required to saturate the water with calcium carbonate may be determined graphically[45] or by a trial and experiment calculation that is practical only with the help of a computer.[46]

TABLE 8.7 CORROSIVITY CHARACTERISTICS AS ADDRESSED BY INDICES[a,b]

Corrosive Characteristics	Langelier Index	Aggressive Index	Driving Force Index
Highly Aggressive	<−2.0	<10.0	<0.01
Moderately Aggressive	−2.0 to < 0.0	10.0 to <12.0	0.01 to <1
Nonaggressive	> 0.0	>12.0	>1

[a] These indices may be used as an approximate measure of the corrosive characteristics of water.

[b] *INTERIM PRIMARY DRINKING WATER REGULATIONS*, U.S. Environmental Protection Agency, Federal Register, Vol. 45, No. 168, Wednesday, August 27, 1980, Rules and Regulations, Washington, D.C., USA.

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[45] *CONTROLLING CORROSION WITHIN WATER SYSTEMS. Obtain by writing Data Processing Department, AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235. Order No. 20203. Price for members $7.70; nonmembers, $9.60.*
or
See Merril, D. T., and Sanks, R. L., "Corrosion Control by Deposition of $CaCO_3$," Journal of American Water Works Association, Part 1, page 592, November 1977; Part 2, page 634, December 1977; and Part 3, page 12, January 1978.

[46] *Computer programs written in BASIC and FORTRAN by Jack Rossum and available from Ken Kerri, Cal State University, Sacramento, 6000 J Street, Sacramento, California 95819. Price $5.00.*

In any event, the calculations are not exact and the chemical dose must be checked by the Marble Test. Only slightly more time is required to find the proper chemical dose by experiment than by the use of the graphical approach or a computer. Results obtained by these methods should be verified by the Marble Test anyway.

To determine the chemical dose experimentally, first calculate the value of pH_s using Larson's formula (Equation 3). Prepare a solution containing 1.000 gram per liter of the chemical to be used (one m*L* will then contain one mg of chemical). Be sure the dilution water does not contain any carbon dioxide. Carbon dioxide may be removed from distilled water by boiling. Deionized water is usually satisfactory. Treat a one liter sample of the water to be tested with one m*L* portions, mixing well, of the chemical solution until the calculated value of pH_s is reached. As one m*L* portions of the chemical solution are added, the pH of the sample will gradually increase until the pH_s value is reached. The degree of saturation is then measured by the Marble Test. Compare the total hardness (mg/*L* as $CaCO_3$) of the water before and after the Marble Test. If the total hardness (as $CaCO_3$) is reduced by more than 10 mg/*L* (the water is supersaturated with $CaCO_3$), try a smaller chemical dose and repeat the procedure until the total hardness is decreased by between 0 and 10 mg/*L* as $CaCO_3$.

To conduct the *MARBLE TEST,*[47] first measure the pH, alkalinity and hardness. Stir a one-half liter sample of the water being tested with approximately 0.5 grams of pulverized marble ($CaCO_3$) for five minutes. Filter the water and again measure the pH, alkalinity, and hardness. A decrease in all three values means the water was supersaturated; an increase in all three values means the water was undersaturated; and no change indicates the water was just saturated with $CaCO_3$. When stirring the sample use a magnetic stirrer and a nearly full, glass-stoppered bottle to prevent a loss or gain of carbon dioxide from the air. Stir fresh water samples as rapidly as possible to be sure that the temperature of the water stays nearly constant during the test.

Water that is just saturated will form a $CaCO_3$ scale only on the cathodic corrosion areas, but water that is well supersaturated will form a scale on all surfaces exposed to flowing water. The thickest scale will form on the surfaces where the water velocity is the highest (up to 5 ft/sec or 1.5 m/sec) because these have the greatest contact of calcium carbonate with the surface. The thickness of scale in water mains seldom exceeds one-eighth inch (3 mm). However, ridges of scale may form transverse (perpendicular) to the flow and very seriously reduce the carrying capacity of the water main. When the velocities are higher (greater than 5 ft/sec or 1.5 m/sec), the scale can be washed or eroded away.

Furthermore, calcium carbonate, unlike most salts, is less soluble in hot water than in cold water. Therefore, even if a water is just saturated as it enters the distribution system, it may become highly supersaturated in hot water systems. Scale has a strong tendency to form on heat transfer surfaces in hot water heaters. Because calcium carbonate does not conduct heat as well as steel, this results in a lowered heating efficiency and in over-heating of the heat transferring metal. Hot water pipes are sometimes found almost completely plugged with a calcium carbonate ($CaCO_3$) deposit. Scale formation can be inhibited by feeding a one-to two-mg/*L* solution of sodium trimetaphosphate.[48] This chemical eventually reverts to the less effective chemical called orthophosphate in the distribution system. The chemical change occurs slowly in cold waters, but quite rapidly in hot water systems.

8.34 Determination of Chemical Feeder Setting

The desirable feeder setting must be established by analysis of the results of your corrosion control program. If the chemical composition of the water is fairly constant, periodic Marble Tests may be used. If the chemical composition of the water is variable, an Enslow Column[49] (Figure 8.9) is more practical.

Unfortunately there are no standards for constructing an Enslow column, nor are any ready-made columns commercially available. To prepare your own Enslow column, refer to Figure 8.9. Use two pieces of 2-inch (50 mm) PVC pipe or glass columns approximately 12 inches (30 cm) long. Fill the first tube (A) with powdered chalk ($CaCO_3$). Fill the second tube (B) with marble or limestone ($CaCO_3$) chips, or coarse silica sand. (The second tube traps any chalk powder swept from the first tube.) The limestone used in either or both tubes should be about the same coarseness as filter sand. This limestone sand can be obtained by breaking up limestone, available from a local building materials supplier, or by breaking up chicken grits obtained from a farm supply store. Use plugs (C) of compacted glass-wool or other suitable material for supporting the straining media. Stopcocks or pinch-cocks (D) are used to regulate the flow. The flask (E) contains the effluent from the Enslow column. Allow this flask to overflow continuously with the calcium carbonate saturated water.

A sample stream of finished water from the plant of approximately ⅛ GPM (0.5 liters/min) is passed through the two columns. This flow should be adjusted to allow for a contact time of two hours, although one hour could be sufficient. A longer contact period should not cause any problems. If the pH increases as the water flows through the columns, the chemical feed should be increased. If the pH decreases, the chemical feed should be decreased. When there is no pH change, the water is just saturated with calcium carbonate ($CaCO_3$). A slight decrease in pH is acceptable, but any increase in pH should be avoided by increasing the chemical dosage. If the alkalinity is measured before and after the water passes through the columns, the amount of increase in alkalinity would indicate the amount of increase required for the chemical feeder setting.

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[47] *Marble Test. See Chapter 21, "Advanced Laboratory Procedures," for detailed procedures on how to perform the marble test.*

[48] *Commercial sodium trimetaphosphate is called sodium hexametaphosphate.*

[49] *Enslow, L. H., "The Continuous Stability Indicator," Water Works & Sewerage, pages 107-108, March, 1939, and pages 283-284, July, 1939.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 370.

8.3H What chemicals may be required for corrosion control if the product of calcium hardness multiplied by the alkalinity (both in mg/*L* as $CaCO_3$) is less than 100?

8.3I What chemicals will be required for corrosion control if the product of calcium hardness multiplied by the alkalinity (both in mg/*L* as $CaCO_3$) is greater than 500?

8.3J How can the proper chemical dose be determined to produce water that is just saturated with calcium carbonate ($CaCO_3$)?

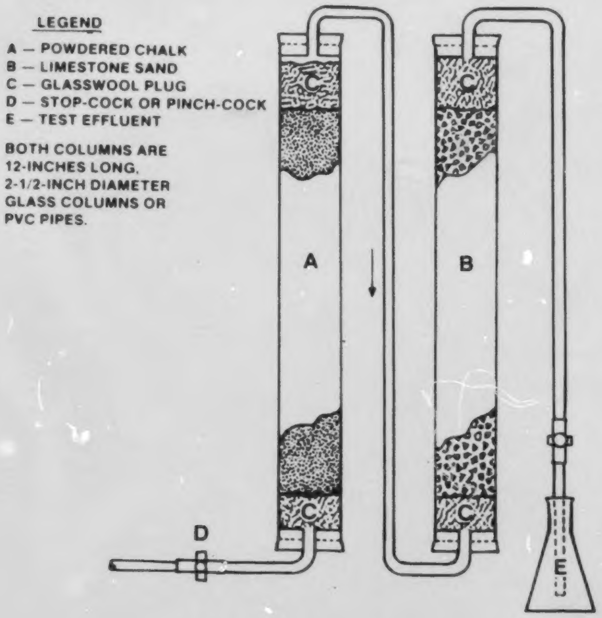
LEGEND
A — POWDERED CHALK
B — LIMESTONE SAND
C — GLASSWOOL PLUG
D — STOP-COCK OR PINCH-COCK
E — TEST EFFLUENT
BOTH COLUMNS ARE 12-INCHES LONG, 2-1/2-INCH DIAMETER GLASS COLUMNS OR PVC PIPES.
C
C
A
B
C
C
D
E

Fig. 8.9 Enslow column

(From Enslow, L. H., "The Continuous Stability Indicator," Water Works and Sewerage, page 108, July, 1939.)

8.35 Zinc, Silica and Polyphosphate Compounds

Certain zinc compounds such as zinc phosphate are capable of forming effective cathodic films that will control corrosion. These zinc compounds are largely proprietary (can only be bought from the owner) and the companies who market these compounds usually supply technical advice and assistance without charge. The zinc compound treatments are generally more expensive than treatment with lime or caustic, but they have the advantage that scale is less apt to be a problem. Do not use zinc phosphate compounds to control corrosion caused by water which will be stored in an open reservoir. The phosphate may cause algal blooms.

Sodium silicate has been used to treat corrosive waters. A solution of sodium silicate ($Na_2O : 3\ SiO_2$) is fed at a rate of approximately 12 mg/*L* as silica is used for the first month, after which the rate is reduced to 8 mg/*L*. This method of treatment is used by individual customers, such as apartment houses and large office buildings, but is not commonly used by water utilities.

Sodium polyphosphates, usually either tetrasodium pyrophosphate ($Na_4P_2O_7$) or so-called sodium hexametaphosphate, have been used for corrosion control. Solutions of these compounds may form protective films, but because they react with calcium, they reduce the effective calcium concentration and thereby actually increase corrosion rates. The major use of these chemicals in water treatment is to control scale formation in waters that are supersaturated with calcium carbonate.

The deterioration of asbestos-cement pipe may be prevented by maintaining calcium carbonate saturation. There is evidence that the zinc treatments are also effective for this purpose as are treatments using traces of iron, manganese, or silica in the water. Any deterioration of asbestos-cement (AC) pipe will cause an increase in pH and calcium of water as it passes through the pipe. Tests for pH and calcium should be performed after the pipe has been in service for two months or longer because all AC pipe contains at least traces of "free lime" which will result in an initial increase in water pH when the pipe is placed in service.[50]

8.36 Cathodic Protection

8.360 Need for Cathodic Protection

Mixers, tanks, flocculators, clarifiers, and filter troughs are frequently constructed of steel and require some sort of corrosion protection. Cathodic protection systems are available in both the manual and automatic types. Automatic cathodic protection systems are preferred because the conductivity (total dissolved solids or TDS) in water can change. Cathodic protection systems are very costly to install. However, it is also very costly to shut down a water treatment process, drain the facility, sand blast metal surfaces, apply paint or a protective coating, and put the facility back on line.

8.361 How the Protection System Works

Cathodic protection is a process used to reduce or inhibit corrosion of metal exposed to water or soil. This process consists of the deliberate act of reversing the electrochemical force to check the destruction that naturally occurs to metals whenever they are buried.

The technique introduces into the natural corrosion cycle an external D.C. (direct current) electrical current sufficiently strong to offset and cancel out the corrosion-producing action. Key to the system is the use of an auxiliary anode of expendable metal which is immersed or buried in the soil or water (called the electrolyte) a predetermined distance from the metal to be protected. Electrical current flowing from the anode to the structure (pipeline, flocculator or clarifier), in precisely the proper flow can exactly counteract corrosion losses.

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[50] *For a fairly complete discussion of this subject, see Schock, ET AL, "Evaluation and Control of Asbestos-Cement Pipe Corrosion," EPA 600/D-81-067 (Feb. 1981). For information on how to obtain a copy of this report, write to Director, Environmental Monitoring and Support Laboratory, Office of Research and Development, 26 West St. Clair Street, Cincinnati, Ohio 45268.*

The application of cathodic protection is an involved process. Factors affecting a corrosion problem include soil conductivity (which varies considerably even within a limited area), soil moisture content, soil and water characteristics, dissolved oxygen content, temperature, seasonal variations of environment (weather), protective coatings, dissimilar metals to be protected, position of other metallic structures and stray currents already present in the ground or water.

All cathodic protection systems pass current through the soil or water from anodes connected to the structure that is to be protected. Two basic methods are used. Sacrificial anode material, such as magnesium or zinc, is used to create a galvanic cell. Such anodes are self-energized and are connected directly to the structure to be protected. These anodes are commonly used where it is desirable to apply small amounts of current at many locations.

The other basic method uses anodes energized by a direct current power supply such as a rectifier (Figure 8.10). This method, commonly referred to as "impressed current," uses relatively inert anodes (usually graphite or high-silicon cast iron) connected directly to the positive terminal of a D.C. (direct current) power supply or rectifier, with the pipe or structure being protected connected to the negative nal. Such systems are generally used where large an of current are required at relatively few locations.

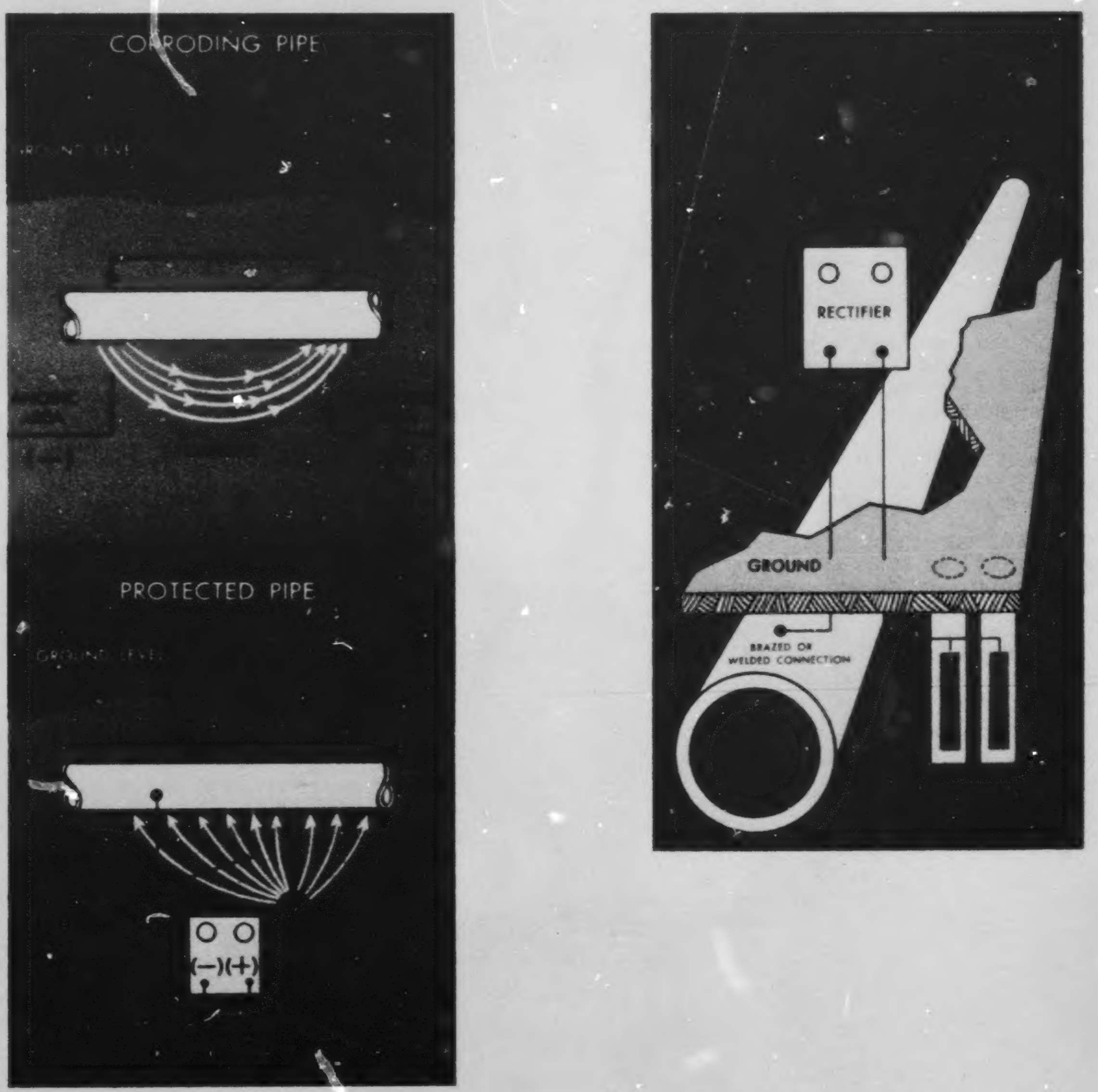

Fig. 8.10 Cathodic protection for buried pipe
(Courtesy of Harco Corporation, Medina, Ohio)

8.362 Equipment

The equipment to be used in any given cathodic protection system is very important. A wide selection of rectifiers is available, including air-cooled, oil immersed, and automatic units. The range of voltage and amperage output is almost infinite. Selection should be based on the particular requirements of the pipe or facilities being protected from corrosion.

Anodes, which serve to distribute the direct current into the earth or water, are manufactured from various metals. Graphite, carbon, high-silicon cast iron, platinum, magnesium, aluminum and zinc alloys are commonly used. Each has its own particular application and proper usage is a determining factor in the success or failure of a cathodic protection system.

8.363 Protection of Flocculators, Clarifiers and Filters

Cathodic protection of flocculators, clarifiers (Figure 8.11) and filters is a very effective means of controlling corrosion since maintenance and repair of protective coatings on these facilities is very difficult. Automatic cathodic protection control devices can provide precise corrosion control under nearly all conditions. The anodes are usually installed below the low-water level with a ten-year anode design life.

8.364 Maintenance

To achieve and maintain a high degree of corrosion control, you must inspect and test the operation of the cathodic protection system and its parts regularly. Regular and proper maintenance is critical because the amount of protective current required to prevent corrosion can vary with changes in the conditions of the coatings on the metallic surfaces, in the chemical characteristics of the water being treated, and the operation of the facilities.

An annual maintenance checkout should include a visual inspection of all anodes, wiring, electrical splices and connections, power units, meters and reference cells. In addition, a complete potential profile should be taken inside the structure to determine the proper automatic controller setting to insure that corrosion control will be maintained automatically on all submerged surfaces throughout the year.

8.37 Removal of Oxygen

Other methods of water treatment for corrosion control are not practical for domestic water systems. Removal of oxygen is used in boilers and in other water heating systems.

8.38 External Corrosion

8.380 Soil Corrosion

Although corrosion on the outside of the water mains is not the responsibility of the water treatment plant operator, there are many smaller systems where the operator is the person who comes closest to being the "corrosion engineer." For this reason some of the factors influencing soil corrosion will be discussed very briefly. The best measure of the corrosivity of soil is the soil resistivity, which is easily measured using one of the several soil resistance meters on the market. The four-point type is the most useful because it can measure average resistivity down to the depth of the pipeline. Some water systems use soil resistivity as an indication of the kind of pipe to install. If the soil resistivity is greater than 5,000 ohms/cm, serious corrosion is unlikely. Steel pipe, with its superior strength and flexibility, may be used under these conditions. If the soil resistivity is below 500 ohms/cm, nonmetallic pipe such as asbestos-cement or PVC is used. Cast iron pipe or cement-mortar lined and coated pipe is used in the intermediate ranges of soil resistivity.

The chemical reactions involved in external corrosion are electrochemical in nature just like those in internal corrosion. The current paths (flows) are not confined to the inside surfaces of the pipe; therefore, galvanic corrosion and electrolysis are relatively more important and cathodic protection is usually practical.

8.381 Corrosion of Steel Imbedded in Concrete

Galvanic corrosion of ferrous (iron) materials under concrete slab floor homes has resulted in millions of dollars in damage before the cause was identified. When steel is imbedded in concrete, it assumes the characteristics of a noble metal. Concrete slabs are always poured over a steel mesh or other reinforcing iron. The electrical resistance of the steel is very small compared to that of concrete, so the

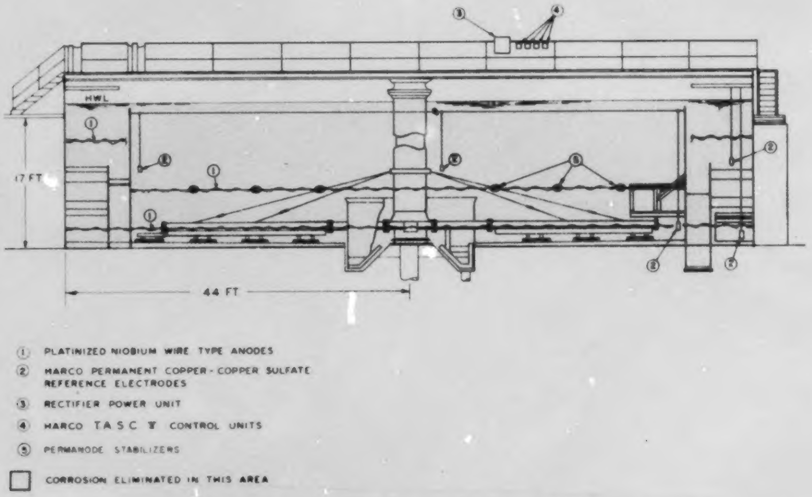
③
④
HWL
①
②
①
②
⑤
②
17 FT
①
②
②
44 FT
① PLATINIZED NIOBIUM WIRE TYPE ANODES
② HARCO PERMANENT COPPER-COPPER SULFATE REFERENCE ELECTRODES
③ RECTIFIER POWER UNIT
④ HARCO T.A.S.C. Ⅱ CONTROL UNITS
⑤ PERMANODE STABILIZERS
☐ CORROSION ELIMINATED IN THIS AREA

Fig. 8.11 Cathodic protection for a clarifier

(Courtesy of Harco Corporation, Medina, Ohio) entire slab behaves as if it were a solid sheet of a noble metal. Since the area of the slabs in a subdivision of slab floor homes is much larger than the area of the pipe, the flow of electrons from the pipes in the area may be fairly large, thus the pipes may be seriously corroded. This problem may be avoided by the use of insulating fittings at the service cock or by the use of plastic service pipe. After the concrete has cured for a few years, the electrical resistance becomes so high that corrosion ceases.

A corrosion problem can develop where a steel water transmission main many miles long runs along side a second main that is coated with cement. If the two mains are connected at pump stations, corrosion problems can develop. At these pump stations a galvanic current of more than 1.0 amperes might be measured. This instance of corrosion may sometimes be controlled by the installation of insulating fittings in order to interrupt the electric circuit.

8.382 Stray Electrical Currents

ELECTROLYSIS[51] is the decomposition of a substance by the passage of an exterior source of D.C. (direct current) electric current (Figure 8.12). The electrolysis of water produces hydrogen and oxygen gases. Chlorine is produced by the electrolysis of sodium chloride solutions, and aluminum is produced by the electrolysis of fused cryolite. When a D.C. current flows (plus to minus) from a metal into soil, the metal is corroded (except for platinum and a few other rare metals under certain conditions).

Alternating current electrolysis will also corrode metals, but its effect is considered (as a rule of thumb) to be only one percent as great as with the same flow of direct current.

Prior to 1940 electrolysis from stray electrical amperage from street car power systems caused a great deal of damage to metallic water mains, but presently there are few such sources of direct current. Modern electric transit systems, however, may pose a serious threat again in the future (Figure 8.13). Electrolysis of water mains can result from stray currents generated by cathodic protection installed by the gas company or other utilities, but engineers who install cathodic protection systems are aware of this possibility and can avoid these problems (Figure 8.14). Electrolysis caused by defective grounding of a customer's piping may be avoided by the use of insulating fittings or using plastic service pipe.

Internal corrosion caused by electrolysis is practically impossible in a system with properly made joints because the resistance of the water in the pipe is in the order of a billion times as great as the resistance of the pipe itself so that corrosion electrical currents must be extremely small by comparison.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 370.

8.3K List one advantage and one limitation of using zinc compounds instead of lime or caustic for corrosion control.

8.3L Where is the application of cathodic protection practical in water treatment plants?

8.3M What is the best measure of the corrosivity of soil?

8.3N How can electrolysis of water mains be caused by other utilities?

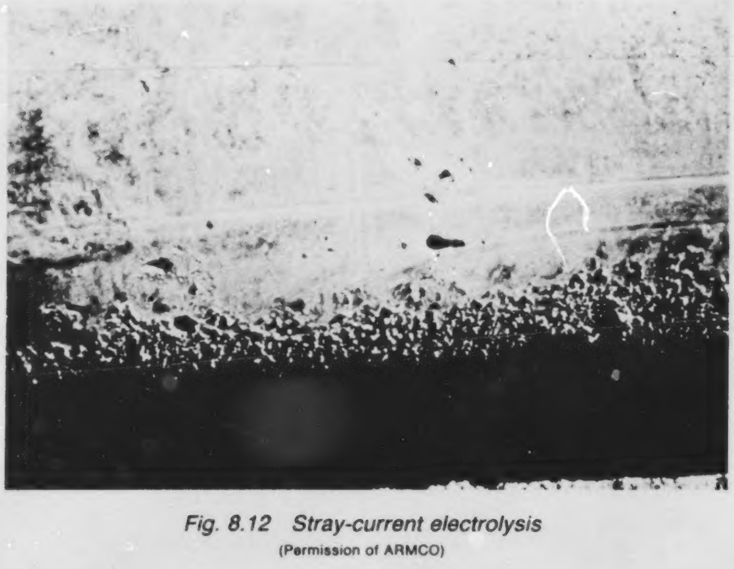

Fig. 8.12 Stray-current electrolysis

(Permission of ARMCO)

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[51] *Electrolysis (e-leck-TRAWL-uh-sis). The decomposition of material by an outside electrical current.*

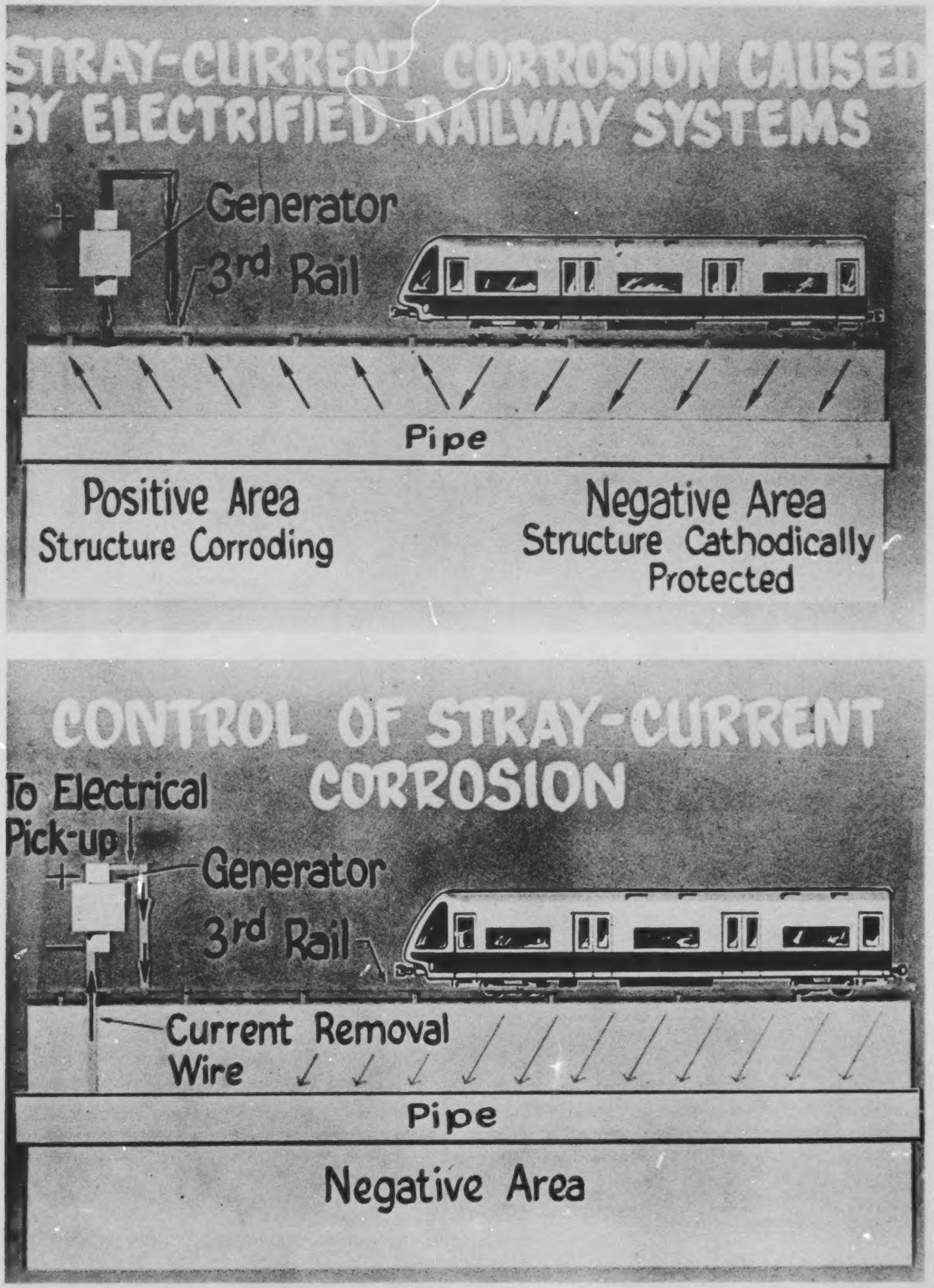
STRAY-CURRENT CORROSION CAUSED BY ELECTRIFIED RAILWAY SYSTEMS
+
-
Generator
3rd Rail
Pipe
Positive Area
Structure Corroding
Negative Area
Structure Cathodically Protected
CONTROL OF STRAY-CURRENT CORROSION
To Electrical Pick-up
+
-
Generator
3rd Rail
Current Removal Wire
Pipe
Negative Area

Fig. 8.13 Stray-current corrosion from electrical transit systems
(Permission of ARMCO)

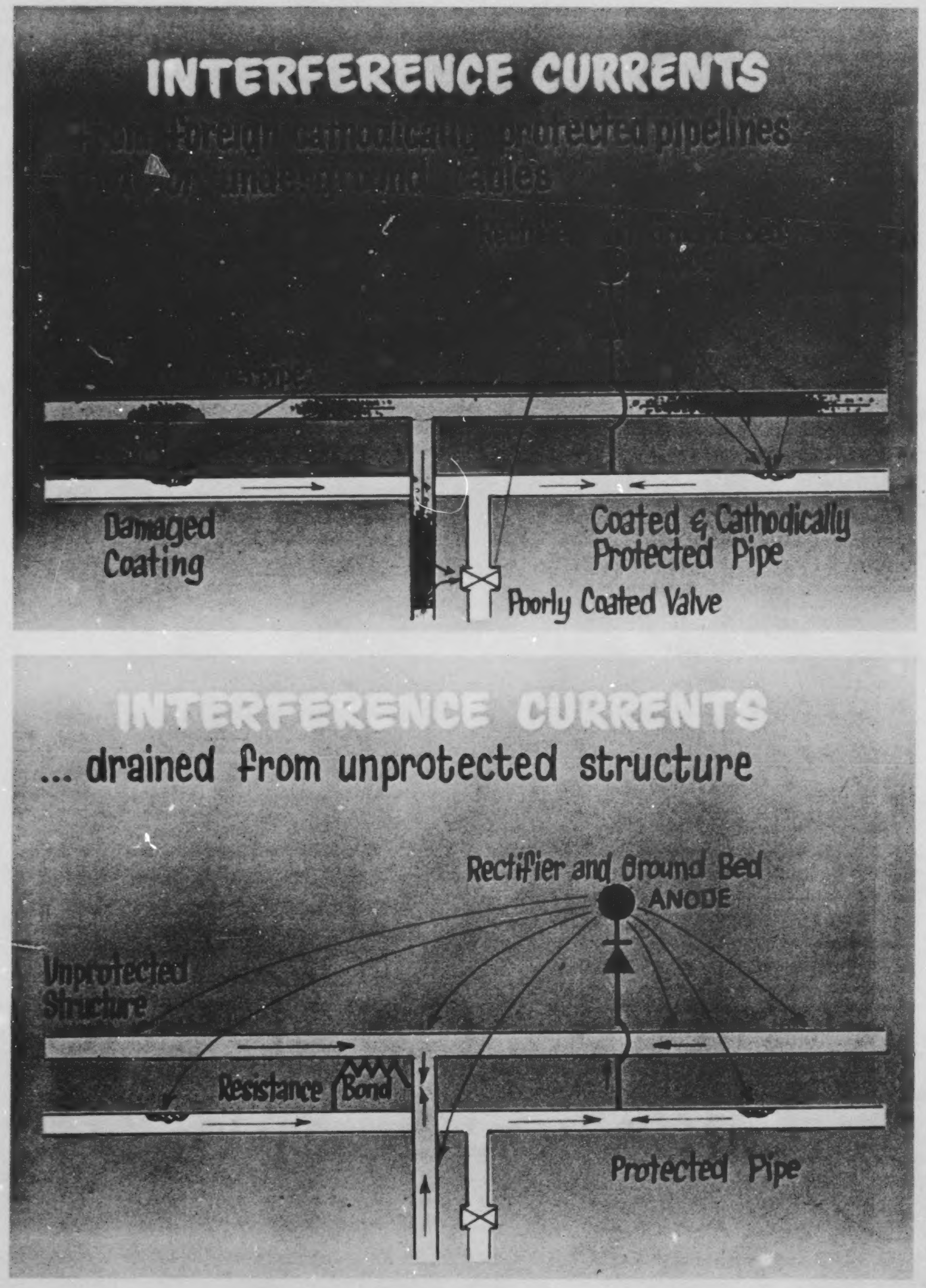
INTERFERENCE CURRENTS
From foreign cathodically protected pipelines
or underground cables
Rectifier and Ground Bed
Pipe
Damaged Coating
Coated & Cathodically Protected Pipe
Poorly Coated Valve
INTERFERENCE CURRENTS
... drained from unprotected structure
Rectifier and Ground Bed
ANODE
Unprotected Structure
Resistance Bond
Protected Pipe

Fig. 8.14 Electrolysis caused by interference currents
(Permission of ARMCO)

8.4 TROUBLESHOOTING

8.40 Internal Pipe Corrosion

Internal corrosion can be detected by rusty water complaints and by examining the insides of pipes for pitting, tubercles, and other evidence of corrosion. To control internal corrosion, treat the water to achieve calcium carbonate saturation.

Select a target pH_s. Dose to this pH. Run a Marble Test on a sample of the treated water. If the pH does not change by more than ±0.2 pH before and after the Marble Test, the target pH_s is satisfactory. If the pH increases during the Marble Test, the target pH_s should be increased by the amount of the pH increase during the Marble Test. Reset the chemical feeder to dose to the new pH. Repeat this procedure until satisfactory results are obtained.

8.41 External Pipe Corrosion

External corrosion is detected by observing pinhole leaks or rust on the outside of pipes. If the rusting pipes were installed with the proper bonds and insulating fittings, cathodic protection can be effective. If cathodic protection is not feasible, the pipe will have to be replaced with PVC, plastic pipe or a cement-coated line.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 370.

8.4A How can internal pipe corrosion be detected?

8.4B How can internal pipe corrosion be controlled?

8.4C How can external pipe corrosion be detected?

8.4D How can external pipe corrosion be controlled?

8.5 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read all of Section A.8, "Pumps." Also work the example problems and check the arithmetic using your calculator.

In Section A.13, "Typical Water Treatment Plant Problems," read and work the problems in Section A.137, "Corrosion Control."

8.6 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 15, "Corrosion and Corrosion Control."
2. *TEXAS MANUAL*, Chapter 11, "Special Water Treatment."
3. *CONTROLLING CORROSION WITHIN WATER SYSTEMS*. Available from Data Processing Department, AWWA, 6666 West Quincy Avenue, Denver, Colorado 80235. Order No. 20203. Price for members, $7.70; nonmembers, $9.60.
4. "Corrosion Control by Deposition of $CaCO_3$ Films, A Practical Approach for Plant Operators," by Douglas T. Merrill and Robert L. Sanks. *JOURNAL AMERICAN WATER WORKS ASSOCIATION;* Part 1, November 1977, pages 592-299; Part 2, December 1977, pages 634-640; and Part 3, January 1978, pages 12-18.
5. "The Harco Corrosion Engineering and Cathodic Protection Library." Write to the Harco Corporation, 1055 West Smith Road, Medina, Ohio 44256 for a listing of technical papers covering topics on:
   1. Fundamental Concepts of Cathodic Protection,
   2. Structure Application Technology,
   3. Cathodic Protection Equipment,
   4. Economics of Cathodic Protection, and
   5. Cathodic Protection and Government Regulations.

   Price is $1.00 per technical paper.

8.7 SUMMARY

Now that you've made it through this chapter on corrosion control — CONGRATULATIONS. You have just finished the toughest chapter in all of our manuals. Corrosion is a very complex topic. We have tried to make this subject as understandable as possible, without over simplifying all of the factors which influence corrosion. Likewise there are many possible solutions to corrosion problems and a combination of solutions may be necessary to solve any corrosion problems in your water treatment and water distribution facilities.

End of Lesson 2 of 2 Lessons
on
CORROSION CONTROL

DISCUSSION AND REVIEW QUESTIONS

Chapter 8. CORROSION CONTROL

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 371. The problem numbering continues from Lesson 1.

7. How can operators determine if the water from their treatment plant is causing corrosion problems?
8. How can a flow test indicate the corrosivity of a water?
9. What chemical tests are helpful to determine the corrosiveness of water?
10. Why is scaling a problem in hot water systems?
11. What is the meaning of a negative Langelier Index?
12. Why can concrete slab floors cause corrosion problems?

SUGGESTED ANSWERS

Chapter 8. CORROSION CONTROL

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 345.

8.0A Problems that can be created by corrosive waters include:

1. Economic losses resulting from corrosion damage,
2. Replacement of water mains,
3. Reduced carrying capacity of mains,
4. Reduction of distribution system pressures,
5. Increases in pump energy costs,
6. Corrosion of lead that may create a serious health hazard, and
7. Customer complaints resulting from rusty water, stained laundry and bad tastes.

8.1A An electrochemical reaction occurs when chemical changes are produced by electricity (electrolysis) or electricity is produced by chemical changes (galvanic action).

8.1B The iron pipe will corrode into the water when it is connected to a copper pipe if the water contains dissolved oxygen.

8.1C Aluminum is unsatisfactory for use in highly alkaline aquatic environments because aluminum may be oxidized (corroded) by hydroxyl ions.

Answers to questions on page 348.

8.1D The current drops significantly in an experimental galvanic cell a few minutes after the switch is first closed because the oxygen molecules in the water next to the copper electrode are quickly used up and can only be replenished by the very slow process of diffusion.

8.1E When brass corrodes (dezincification), the copper plates out as a mass of spongy copper having nearly the same shape as the original brass.

8.1F The corrosion rate is directly proportional to the dissolved oxygen concentration.

8.1G A "dangerous" corrosion inhibitor is one that acts on the anode reaction. If not quite enough inhibitor is added, severe pitting will result and corrosion will be worse than if no inhibitor had been added.

8.1H If a copper service line is connected to a steel water main, the cathode area is large relative to the anode and corrosion will occur at the anode.

Answers to questions on page 349.

8.1I When salinity increases, the rate of corrosion increases.

8.1J A thin film or coating of calcium carbonate can drastically inhibit corrosion.

8.1K "Erosion corrosion" in copper tubing is caused by water velocities over five feet per second.

Answers to questions on page 351.

8.1L The oxygen concentration cell is the most common type corrosion cell.

8.1M An oxygen concentration cell can be started in the dead end of a water main.

8.1N A tubercle is a small protective crust of rust which builds up over a pit caused by the loss of metal from corrosion.

8.1O Pits can be started on a metallic surface under water by anything that will shield the metal surface from dissolved oxygen in the water, such as bits of clay, dirt, sand or a colony of bacteria. Also impurities in the metal may cause a local anode to form.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 352.

8.2A Water systems are prohibited from serving corrosive water because of the possibility of corroding lead or other toxic metals into the water.

8.2B Corrosion rates may be measured by inserting steel specimens called "coupons" in water mains. After a period of time, usually a month or two, the coupons are removed and the loss of weight is measured.

8.2C Leaks in water mains can often be detected by the observation of wet spots above the water main.

8.2D A film of calcium carbonate too thin to see can be detected by placing a drop of dilute hydrochloric (HCl) acid on an obvious cathodic area and observing the area for effervescence (bubbles).

Answers to questions on page 354.

8.2E Loss of dissolved oxygen in the water flowing in a distribution system indicates either that the water contains organic matter or that corrosion is occurring.

8.2F Toxic metals that may enter drinking waters from the customer's plumbing due to corrosive water include (1) lead from soldered fittings used with copper tubing and (2) cadmium found in zinc used for galvanizing steel pipes.

8.2G The marble test is used to determine if water is undersaturated or supersaturated with calcium carbonate.

8.2H Rusty or red water complaints indicate that the water is corrosive.

Answers to questions on page 356.

8.3A The corrosivity of a water is often reduced by treating the water so that the water is saturated or slightly supersaturated with calcium carbonate.

8.3B The corrosivity of water may be reduced by adding quicklime (CaO), hydrated lime ($Ca(OH)_2$), caustic (NaOH) or soda ash (Na_2CO_3).

Answers to questions on page 360.

8.3C A Driving Force Index (D.F.I.) of less than one (1) indicates that the water is undersaturated with calcium carbonate and therefore corrosive.

8.3D pH_s is that pH where water is just saturated with calcium carbonate.

8.3E Some waters do not have a true pH_s value because they contain insufficient calcium and/or carbonate to become saturated regardless of their pH.

8.3F The Langelier Index is defined by the equation
L.I. = $pH - pH_s$.

8.3G

Known		**Unknown**
Water Temp., °C	= 10°C	pH_s
TDS, mg/*L*	= 100 mg/*L*	
Alky, mg/*L*	= 80 mg/*L*	
Ca Hardness, mg/*L*	= 40 mg/*L*	

1. Find the formula values from the tables.

   From Table 8.3 for a water temperature of 10°C, A = 2.20.

   From Table 8.4 for a TDS of 100 mg/*L*, B = 9.75.

   From Table 8.5 for Alky of 80 mg/*L* and Ca of 40 mg/*L*, log (Ca^{2+}) = 1.60, and log (Alky) = 1.90.

2. Calculate pH_s.

$$\begin{aligned} pH_s &= A + B - \log(Ca^{2+}) - \log(\text{Alky}) \\ &= 2.20 + 9.75 - 1.60 - 1.90 \\ &= 8.45 \end{aligned}$$

Answers to questions on page 362.

8.3H If the product of calcium hardness multiplied by the alkalinity (both in mg/*L* as $CaCO_3$) is less than 100, both lime and carbon dioxide may be required.

8.3I If the product of calcium hardness multiplied by the alkalinity (both in mg/*L* as $CaCO_3$) is greater than 500, either lime or caustic (NaOH) may be used. Soda ash (Na_2CO_3) should not be used because of the expense.

8.3J The proper chemical dose to produce water that is just saturated with calcium carbonate ($CaCO_3$) can be determined by (1) graphical methods, (2) trial and error calculations with a computer, and (3) use of the Marble Test or an Enslow column.

Answers to questions on page 365.

8.3K List one advantage and one limitation of using zinc compounds over lime or caustic for corrosion control.

ADVANTAGE

1. Scale is less apt to be a problem with zinc compounds.
2. Prevent deterioration of asbestos-cement pipe.

LIMITATION

Zinc compounds are generally more expensive than treatment with lime or caustic.

8.3L Cathodic protection is practical in water treatment plants to protect mixers, tanks, flocculators, clarifiers, and filter troughs.

8.3M The best measure of the corrosivity of soil is the soil resistivity, which is measured by a soil resistance meter.

8.3N Electrolysis of water mains can result from currents generated by cathodic protection installed by the gas company or other utilities.

Answers to questions on page 368.

8.4A Internal pipe corrosion can be detected (1) by rusty water complaints and (2) by examining the insides of pipes for pitting, tubercles, and other evidence of corrosion.

8.4B Internal pipe corrosion can be controlled by treating the water to achieve calcium carbonate saturation.

8.4C External pipe corrosion is detected by observing for pinhole leaks or rust on the outside of pipes.

8.4D External pipe corrosion can be controlled by the installation of the proper electrical bonds and insulating fittings, and the use of cathodic protection.

OBJECTIVE TEST

Chapter 8. CORROSION CONTROL

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE - FALSE

1. Metallic corrosion in potable water is *ALWAYS* the result of an electrochemical reaction.
   1. True
   2. False

2. The cathode and anode reactions in corrosion occur at the same location.
   1. True
   2. False

3. A galvanic cell occurs when two dissimilar metals such as iron and copper are connected.
   1. True
   2. False

4. When an electrical switch is open in a circuit connected to two electrodes, current will flow between two electrodes immersed in an electrolyte.
   1. True
   2. False

5. Dissolved oxygen must be present for corrosion to occur.
   1. True
   2. False

6. If there are "pinholes" in the protective coating of a paint over an anodic area, the corrosive attack at these points will be much greater than it would have been with no paint coating.
   1. True
   2. False

7. A thin film or coating of calcium carbonate can retard corrosion.
   1. True
   2. False

8. Galvanic cells are a more common corrosion cell than oxygen concentration cells.
   1. True
   2. False

9. Use of lime for corrosion may add some hardness to the water.
   1. True
   2. False

10. Every water has a pH_s value.
    1. True
    2. False

11. Calcium carbonate is more soluble in hot water than in cold water.
    1. True
    2. False

12. The chemical reactions involved in external pipe corrosion are electrochemical in nature and similar to those in internal corrosion.
    1. True
    2. False

13. Concentrated sulfuric acid is a very dangerous chemical and must be handled with great care.
    1. True
    2. False

14. Ferric hydroxide builds up a protective crust over pits caused by the loss of metal from corrosion.
    1. True
    2. False

15. Calculations for chemical doses of calcium carbonate are exact.
    1. True
    2. False

MULTIPLE CHOICE

16. Factors influencing the corrosion rate include
    1. Dissolved oxygen in the water.
    2. Cathode film formation.
    3. Cathode metal.
    4. Salinity.
    5. Time of day.

17. A water from a surface supply may be identified as corrosive by which of the following tests?
    1. Chemical test.
    2. Flow test through black iron pipe.
    3. Hardness test.
    4. Leak test.
    5. Marble test.

18. Possible solutions to corrosion problems include
    1. Anodic protection.
    2. Calcium carbonate saturation.
    3. Cathodic protection.
    4. Dissolved oxygen saturation.
    5. Installation of plastic pipe.

19. Adverse effects caused by corrosion include
    1. Coliform regrowth.
    2. Economic losses.
    3. Increased pump energy costs.
    4. Reduction in water main capacity.
    5. Reduction in rusty water complaints.

20. Hydrogen ion is extremely active (corrosive) at pH values below
    1. 4.
    2. 6.
    3. 7.
    4. 8.
    5. 10.

21. Water velocities in copper tubing in excess of ______ can cause erosion corrosion.
    1. 0 ft/sec.
    2. 2 ft/sec.
    3. 3.5 ft/sec.
    4. 4 ft/sec.
    5. 5 ft/sec.

22. Tubercles can form in pipes made of
    1. Asbestos cement.
    2. Clay tile.
    3. Glass.
    4. Iron.
    5. Plastic.

23. Chemicals that are added to water to reduce corrosivity include
    1. Calcium chloride.
    2. Calcium hydroxide.
    3. Sodium carbonate.
    4. Sodium chloride.
    5. Sodium hydroxide.

24. What conditions must be met in order for a calcium carbonate (limestone) film to form?
    1. The Langelier Index must be negative.
    2. The pH cannot be too high.
    3. The water must be supersaturated with calcium carbonate.
    4. The water must contain bicarbonate ions.
    5. There must be a negative Driving Force Index.

25. Oxygen concentration cells may be started by
    1. Applying an electromotive force.
    2. Bubbles of oxygen in the water.
    3. Drop of soldering flux.
    4. Impurities in a metal pipe.
    5. Microbiological growth.

26. Chemical reactions inside tubercles in iron pipe cause
    1. Calcium carbonate films to form.
    2. Complaints.
    3. Milky water.
    4. Rotten egg odors.
    5. Rust.

27. Indices of calcium carbonate saturation include
    1. Driving Force Index.
    2. Langelier Index.
    3. Larson Index.
    4. Rossum Index.
    5. Ryznar Index.

28. The chemical dose required to saturate a water with calcium carbonate may be determined by
    1. Calculating hydraulic loadings.
    2. Graphical methods.
    3. Marble test.
    4. Measuring the dissolved oxygen concentration.
    5. Trial and error calculations using a computer.

29. The best measure of the corrosivity of soil is the soil
    1. Electrolysis.
    2. Galvanic corrosion.
    3. Oxygen concentration cell.
    4. Polarization.
    5. Resistivity.

30. Find the pH_s of a water at 20°C having a TDS of 400 mg/*L*, alkalinity of 200 mg/*L* as $CaCO_3$ and a calcium hardness of 70 mg/*L* as $CaCO_3$.
    1. 4.14
    2. 7.77
    3. 8.45
    4. 9.86
    5. 11.91

31. What horsepower must a pump deliver to water which must be lifted 80 feet? The flow is 50 GPM.
    1. 0.9 HP
    2. 1.0 HP
    3. 50 HP
    4. 60 HP
    5. 4000 HP

32. If the required water horsepower of a pump is 60 HP, what must be the motor horsepower if the efficiency of the pump is 75 percent and the efficiency of the motor is 90 percent?
    1. 40.5 HP
    2. 50 HP
    3. 72 HP
    4. 75 HP
    5. 89 HP

33. How many kilowatt-hours per day are required by a pump with a motor horsepower of 40 horsepower when the pump operates 24 hours per day?
    1. 716 kw-hrs/day
    2. 801 kw-hrs/day
    3. 960 kw-hrs/day
    4. 1075 kw-hrs/day
    5. 1287 kw-hrs/day

34. What is the wire-to-water efficiency of a pump if the water horsepower is 7.2 horsepower and the power input is 11.1 horsepower?
    1. 55%
    2. 60%
    3. 65%
    4. 70%
    5. 75%

End of Objective Test

CHAPTER 9

TASTE AND ODOR CONTROL

by

Russ Bowen

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OBJECTIVES

Chapter 9. TASTE AND ODOR CONTROL

Following completion of Chapter 9, you should be able to:

1. Explain the importance of taste and odor control,
2. Identify causes of tastes and odors,
3. Locate sources of tastes and odors,
5. Treat or eliminate tastes and odors, and
6. Develop a taste and odor control strategy.

GLOSSARY

Chapter 9. TASTE AND ODOR CONTROL

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ADSORBATE (add-SORE-bait) ADSORBATE

The material being removed by the adsorption process.

ADSORBENT (add-SORE-bent) ADSORBENT

The material (activated carbon) that is responsible for removing the undesirable substance in the adsorption process.

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AERATION (air-A-shun) AERATION

The process of adding air to water. Air can be added to water by either passing through water or passing water through air.

AEROBIC (AIR-O-bick) AEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is present in the water.

AIR STRIPPING AIR STRIPPING

A treatment process used to remove dissolved gases and volatile substances from water. Large volumes of air are bubbled through the water being treated to remove (strip out) the dissolved gases and volatile substances.

ALGAE (AL-gee) ALGAE

Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.

AMBIENT TEMPERATURE (AM-bee-ent) AMBIENT TEMPERATURE

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

ANAEROBIC (AN-air-O-bick) ANAEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is *NOT* present in water.

BACTERIA (back-TEER-e-uh) BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BIOLOGICAL GROWTH BIOLOGICAL GROWTH

The activity and growth of any and all living organisms. Microbial growth is the same as biological growth.

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce cancer in an organism.

CHLOROPHENOLIC (klor-o-FEE-NO-lick) CHLOROPHENOLIC

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

CHLORORGANIC (clor-or-GAN-nick) CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

DECHLORINATION (dee-KLOR-uh-NAY-shun) DECHLORINATION

The deliberate removal of chlorine from water. The partial or complete reduction of residual chlorine by any chemical or physical process.

DECOMPOSITION DECOMPOSITION

The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) will produce much less objectionable tastes and odors.

DEGASIFICATION (dee-GAS-if-uh-KAY-shun) DEGASIFICATION

A water treatment process which removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic alge with a rigid (box-like) internal structure consisting mainly of silica.

ENZYMES (EN-zimes) ENZYMES

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

EUTROPHICATION (you-TRO-fi-KAY-shun) EUTROPHICATION

The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.

FLAGELLATES (FLAJ-el-LATES) FLAGELLATES

Microorganisms that move by the action of tail-like projections.

FUNGI (FUN-ji) FUNGI

Mushrooms, molds, mildews, rusts, and smuts that are small nonchlorophyll-bearing plants lacking roots, stems or leaves. They occur in natural waters and grow best in the absence of light. Their decomposition may cause objectionable tastes and odors in water.

HYDROPHILIC (HI-dro-FILL-lick) HYDROPHILIC

Having a strong affinity (liking) for water. The opposite of HYDROPHOBIC.

HYDROPHOBIC (HI-dro-FOE-bick) HYDROPHOBIC

Having a strong aversion (dislike) for water. The opposite of HYDROPHILIC.

IMHOFF CONE IMHOFF CONE

A clear, cone-shaped container marked with graduations. The cone is used to measure the volume of settleable solids in a specific volume (usually one liter) of water.

INORGANIC INORGANIC

Material such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

INTERFACE INTERFACE

The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

KJELDAHL NITROGEN (KELL-doll) KJELDAHL NITROGEN

Nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl Method.

METABOLISM (meh-TAB-uh-LIZ-um) METABOLISM

(1) The biochemical processes in which food is used and wastes are formed by living organisms.

(2) All biochemical reactions involved in cell formation and growth.

MICROBIAL GROWTH MICROBIAL GROWTH

The activity and growth of microorganisms, such as bacteria, algae, diatoms, plankton and fungi. Biological growth is the same as microbial growth.

MICROORGANISMS (MY-crow-OR-gan-IS-zums) MICROORGANISMS

Living organisms that can be seen individually only with the aid of a microscope.

NPDES PERMIT NPDES PERMIT

National **P**ollutant **D**ischarge **E**limination **S**ystem permit is the regulatory agency document designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

NEPHELOMETRIC (NEFF-el-o-MET-rick) NEPHELOMETRIC

A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

OLFACTORY FATIGUE (ol-FAK-tore-ee) OLFACTORY FATIGUE

A condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor.

ORGANIC ORGANIC

Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OZONATION (O-zoe-NAY-shun) OZONATION

The application of ozone to water for disinfection or for taste and odor control.

PERCOLATION (PURR-ko-LAY-shun) PERCOLATION

The slow passage of water through a filter medium; or, the gradual penetration of soil and rocks by water.

PHENOLIC COMPOUNDS (FEE-noll-LICK) PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene.

PHOTOSYNTHESIS (foe-tow-SIN-thuh-sis) PHOTOSYNTHESIS

A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen and additional plant material, using sunlight for energy. All green plants grow by this process.

PLANKTON PLANKTON

(1) Small, usually microscopic, plants (phytoplankton) and animal (zooplankton) in aquatic systems.

(2) All of the smaller floating, suspended or self-propelled organisms in a body of water.

PUTREFACTION (PEW-truh-FACK-shun) PUTREFACTION

Biological decomposition of organic matter, with the production of ill-smelling and tasting products, associated with anaerobic (no oxygen present) conditions.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

RESPIRATION RESPIRATION

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

SATURATION SATURATION

The condition of a liquid (water) when the liquid has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

SLURRY (SLUR-e)	SLURRY
A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).	
SUPERCHLORINATION (SUE-per-KLOR-uh-NAY-shun)	SUPERCHLORINATION
Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.	
SUPERNATANT (sue-per-NAY-tent)	SUPERNATANT
Liquid removed from settled sludge. Supernatant commonly refers to liquid between the sludge on the bottom and the water surface of a basin or container.	
SUPERSATURATION	SUPERSATURATION
An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation condition for the substance.	
THRESHOLD ODOR NUMBER	THRESHOLD ODOR NUMBER
TON. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.	
TOXIC (TOX-ick)	TOXIC
A substance which is poisonous to an organism.	
VOLATILE (VOL-uh-tull)	VOLATILE
A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.	

CHAPTER 9. TASTE AND ODOR CONTROL

(Lesson 1 of 3 Lessons)

9.0 IMPORTANCE OF TASTE AND ODOR CONTROL

Tastes and odors in drinking water are among the most common and difficult problems that confront waterworks operators. In nationwide surveys 20 percent of the people served by municipal water systems rate their water as having an objectionable taste and/or odor. Of water utilities surveyed, 80 percent responded that treatment for tastes and odors was necessary at least occasionally. Taste and odor problems may occur locally on a persistent, seasonal, occasional, or infrequent basis. Regardless of the frequency or type of taste and odor problem that a utility may face, these survey results indicate that taste and odor problems are widespread. Most water treatment plant operators will have to deal with a taste and odor problem at some time during their career.

Taste and odor, along with "colored water" complaints, are the most common types of water quality complaints received by a water utility. This is because the average consumer uses three senses to evaluate water: sight, smell, and taste. If the water looks dirty or colored, smells bad, or has an objectionable taste, the consumer will rate it as poor quality water. This is true whether or not any health-related problem exists.

Taste and odor (T&O) problems are likely to have significant effects on a water utility when they occur. First, numerous complaints must be handled. This requires a great deal of staff time, creates a sense of frustration for both the consumer and for office personnel, and may well require time of operators who could better be used to solve the problem rather than deal with the effects of the problem.

Water that has an objectionable taste or odor is not desirable to the general public. This may cause a number of consumers to begin purchasing bottled water for drinking purposes. Other consumers may switch to alternative water supplies, such as old, poorly maintained private wells which may not be as safe as the public supply. People could unknowingly use water which may be hazardous because it has a more pleasing taste or smell than the public water supply.

Perhaps the most damaging effect of a taste and odor episode is the loss of public confidence in the water utility's ability to provide a safe, high quality water. Serious loss of confidence may later result in funding restrictions and increased public relations problems for the utility.

Because of the widespread occurrence of taste and odor problems in public drinking water supplies and the serious effects of these types of problems on the utility, taste and odor control is an area in which training of all water treatment operators is vitally necessary.

The secret to successful taste and odor control is to *PREVENT TASTES AND ODORS FROM EVER DEVELOPING.* This means control of algae in water supply reservoirs and preventive treatment. You must treat for tastes and odors *BEFORE* the problem occurs.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 407.

9.0A How frequently may taste and odor problems occur at a water treatment plant?

9.0B What are the most common types of water quality complaints received by a water utility?

9.0C What is the most damaging effect of taste and odor problems for a water utility?

9.1 CAUSES OF TASTES AND ODORS

9.10 Types of Causes

Taste and odor problems may arise from such diverse causes and may be the result of such a variety of combinations of factors that any discussion of the reasons for objectionable tastes and odors in drinking water must necessarily be general in nature. Determining the cause of any taste and odor episode may be extremely difficult, and in many cases no definite answers are every found. Nonetheless, some general understanding of conditions which can contribute to taste and odor problems is useful in trying to prevent and treat water of objectionable quality.

Tastes and odors can be the result of natural or manmade conditions that exist anywhere within the total water supply system. Raw water sources, conveyance facilities, treatment plants, chlorination stations, finished storage reservoirs, distribution systems, and consumer plumbing have all been identified as sources of tastes and odors. Each water system must be evaluated individually since each will have unique characteristics that may significantly affect water quality.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 407.

9.1A List the two types of tastes and odors in a water system.

9.1B Where could taste and odor conditions develop in a water supply system?

9.11 Natural Causes

9.110 Biological Growths[1]

Organisms which grow in water or in the sediments of lakes, reservoirs, and rivers are significant contributors to tastes and odors experienced by water utilities. Various types of bacteria, algae, diatoms, flagellates, or fungi have all been reported as the cause of problems at waterworks across the nation. Biological growths leading to objectionable tastes and odors can occur during any time of the year and in any area of a water system.

Microbial populations can contribute to unpleasant tasting and smelling water in two general ways. As microorganisms grow and multiply, they produce metabolic by-products. These by-products are released into the water and some may lead to the deterioration of taste and odor quality. The concentration of compounds produced by microorganisms is generally very low and may be measured in nanograms per liter (parts per trillion parts). However, even such extremely low levels of these materials may result in many taste and odor complaints.

Cellular material of common aquatic microorganisms present in a drinking water supply can also be responsible for taste and odor complaints. As the microorganisms grow, organic matter accumulates within the cells. As long as the organisms are healthy, these cellular components are retained and usually do not affect the taste or odor of a water. When the population begins to die off, either as a result of natural processes or treatment, the cells rupture and the cellular materials are released into the water. This is one reason why, in some cases, water has better taste and odor qualities before being treated than after treatment.

This phenomenon (die off causing tastes and odors) must be considered in developing plans for copper sulfate treatment of reservoirs. Even relatively high *PLANKTON*[2] counts do not necessarily indicate that treatment is either required or that it will be beneficial. A large total plankton count may be the result of low numbers of many different types of organisms. This can indicate a well balanced, diversified plankton community that does not pose a threat to taste and odor quality. Treating with copper sulfate may disrupt this natural balance, allowing an objectionable organism to predominate, and may create a taste and odor problem by causing the release of cellular components from killed organisms that otherwise would not have had a detrimental effect on water quality.

Microbial decomposition of organic matter in a water supply may also create offensive tastes and odors through a combination of both metabolic by-product formation and release of cellular materials. Following an algal bloom, significant natural die-off of the predominant organism may result in the release of cellular materials with objectionable qualities. The resulting tastes and odors can be further worsened by the growth of other microorganisms feeding on the dying algal mass. This secondary growth may lead to the production of obnoxious metabolic by-products.

While *DECOMPOSITION*[3] is a critical step in the continuous cycling of nutrients through nature, it can have serious consequences on water quality. For this reason, raw water treatment programs are only useful if operated to prevent massive microbial growths. If treatments are begun only after large populations have developed, the effect may be to accelerate the decomposition process and worsen a taste and odor outbreak. Frequent monitoring of plankton populations in source waters will provide early warning of the need for preventive treatment such as the application of copper sulfate.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 407.

9.1C Where and when can an operator expect microbial growths to occur which will lead to objectionable tastes and odors?

9.1D What are the two general ways in which microbial populations can contribute to unpleasant tasting and smelling water?

9.1E Why does treatment that takes place after a large microbial population growth has occurred sometimes cause a taste and odor problem to get worse?

9.111 Environmental Conditions

The effects of lake and reservoir stratification on water quality were discussed in Chapter 3. The depletion of oxygen within reservoirs provides suitable conditions for the growth of microorganisms capable of producing compounds, such as hydrogen sulfide, which are very objectionable to consumers. The information in Chapter 3 should be reviewed as it relates to the causes of taste and odor problems in drinking water supplies drawn from large reservoirs.

Oxygen-poor conditions in reservoirs, ponds, rivers, and canals can also result indirectly from a high nutrient loading of the water due to inflow of many types of pollutants, particularly of organic matter and compounds containing nitrogen and phosphorus. Increased nutrient levels (called *EUTROPHICATION*[4]) may result from either natural conditions or from human activity within the watershed.

---

[1] *Biological Growths. The activity and growth of any and all living organisms. Microbial growth is the same as biological growth.*

[2] *Plankton. (1) Small, usually microscopic, plants (phytoplankton) and animals (zooplankton) in aquatic systems. (2) All of the smaller, floating, suspended or self-propelled organisms in a body of water.*

[3] *Decomposition. The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) will produce much less objectionable tastes and odors.*

Pollutants themselves normally do not cause the oxygen concentration in the water to decrease. Microorganisms capable of growing on the organic materials (pollutants) are responsible for depletion of the oxygen following nutrient enrichment from runoff. Microbial populations are relatively low in unpolluted waters, and the rate of oxygen transfer from the atmosphere to the water is sufficient to prevent oxygen-poor conditions from developing. When available nutrient concentrations increase, rapid microbial growth consumes dissolved oxygen at a rate faster than it can be replaced from the air. Oxygen-poor conditions in water following increased nutrient loading are the result of this rapid microbial growth.

Blooms of *PHOTOSYNTHETIC*[5] algae resulting from increased nutrient concentrations, suitable water temperatures, and favorable sunlight can cause both oxygen depletion and oxygen supersaturation in water during a 24-hour period. The process of photosynthesis occurs during daylight hours and results in oxygen being released into the water. Large populations of algae can produce oxygen faster than it can escape to the atmosphere, leading to afternoon dissolved oxygen levels higher than would normally occur in the absence of major algal activity. When dissolved oxygen levels in water exceed normal saturation levels the condition is known as supersaturation.

At night, the algal photosynthesis stops and respiration begins. Respiration is the metabolic process that consumes oxygen and releases carbon dioxide. In the dark hours, the algae use the available oxygen at a rate faster than it can be replenished from the air. By the early morning hours almost all of the dissolved oxygen may have been consumed. This pattern of supersaturation and depletion is known as the diurnal dissolved oxygen cycle and is shown in Figure 9.1. (Notice that the graph in Figure 9.1 shows the *PERCENT* of oxygen saturation during the 24-hour period. This is because oxygen saturation changes with both temperature and elevation. At sea level, for example, oxygen saturation at 10°C is approximately 11 mg/*L* while at 20°C it is only about 9 mg/*L*.)

The importance of diurnal oxygen fluctuations in water is that significantly different conditions can and do exist from day to night. These differences may have a major effect on taste and odor quality. Oxygen depletion during the night may result in fish kills and die-off of other aquatic vegetation which will produce foul tastes and odors in water. Oxygen-poor conditions during darkness may also allow anaerobic organisms to become established and contribute to a general degradation of the esthetic qualities of the water.

From an operations viewpoint, significant dissolved oxygen fluctuations caused by algae in raw water will also be accompanied by changes in the pH. When algae produce oxygen, carbon dioxide (CO_2) is removed from the water and the pH will increase during the daylight hours. At night during the respiration process, algae will consume oxygen and release carbon dioxide which will lower the pH. These changes in pH caused by increases and decreases of carbon dioxide will influence the chemical doses required to effectively treat the water (coagulation-flocculation, disinfection, corrosion control).

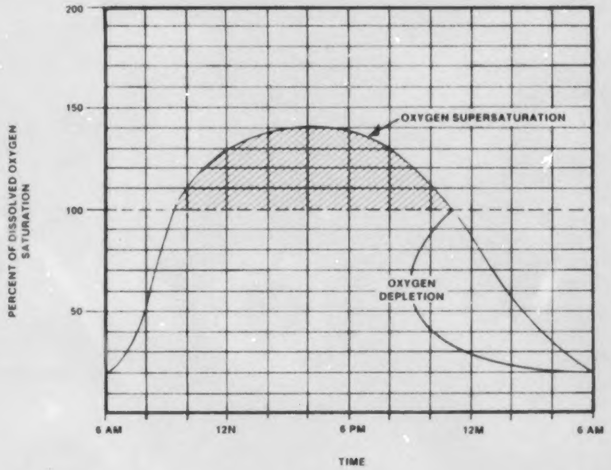

Fig. 9.1 Diurnal variation in dissolved oxygen concentrations

A special case of nutrient enrichment can occur at water treatment plants designed to recycle water used in filter backwashing and settling basin sludge removal. Typically, some type of settling basin or lagoon is provided to allow the sludge to settle before the water is decanted off (separated) and returned to the plant influent. These sludge lagoons produce a water supply in which nutrients previously removed by treatment are concentrated. Microbial populations can flourish in these facilities, and unless careful management is practiced, severe taste and odor problems can originate from sludge settling lagoons. This is especially true when the *DECANT WATER*[6] passes through the plant as a high percentage of total plant flow over extended periods. Frequent treatment with copper sulfate and rotation of sludge lagoons where multiple units are available, or removal of sludge to separate drying facilities are all appropriate methods for controlling the taste and odor problems associated with these water recovery systems.

Natural runoff may also lead to tastes and odors by substantially increasing flow velocities in rivers and canals. Sediments deposited on the bottom of channels during low-flow periods may be resuspended by scouring action and transported into the treatment plant. When present in the plant influent, bottom sediments may impart septic, musty, or earthy tastes and odors to the drinking water supply. Problems associated with high flow conditions may subside as runoff decreases, or may persist for several weeks until natural settling redeposits the suspended material on the channel bottom.

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[4] *EUTROPHICATION (you-TRO-fi-KAY-shun). The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.*

[5] *Photosynthesis (foe-tow-SIN-THUH-sis). A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen, and additional plant material, using sunlight for energy. All green plants grow by this process.*

[6] *Decant Water. Water that has separated from sludge and is removed from the layer of water above the sludge.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 407.

9.1F How can the nutrient levels in a water supply be increased?

9.1G What types of materials in runoff waters can lead to oxygen depletion?

9.1H What causes the diurnal dissolved oxygen cycle?

9.12 Man-Made Causes of Tastes and Odors

9.120 Types of Sources

Many of man's activities in the environment lead to objectionable tastes and odors in public water systems. Increased awareness of environmental degradation has led to many new pollution control regulations at both the state and federal levels. These regulations have significantly improved conditions in many of the nation's waterways, but discharges upstream of municipal intake facilities or into raw water storage reservoirs continue to be contributing factors in many taste and odor experiences.

Types of pollution which may enter a municipal water supply upstream of the water treatment plant and result in water quality degradation include inadequately treated municipal wastewaters, domestic wastes from individual homes, industrial discharges, urban runoff, chemical spills, agricultural wastes (manure) and irrigation runoff. Tastes and odors may be created by these discharges directly, or may develop because of microbial activities associated with the pollution.

9.121 Municipal Wastewaters

Inadequately treated municipal wastewaters may enter a water supply due to a process failure at the wastewater treatment plant, mechanical breakdowns, or overloading of the facility. Some older municipal wastewater treatment plants discharge inadequately treated effluent during periods of heavy precipitation because of high flows (inflow and infiltration or I & I) from combined sanitary sewer and storm drain systems. Other wastewater works simply do not have the extensive facilities required to maintain the effluent quality necessary to prevent degradation of the receiving water.

Individual wastewater disposal systems in rural areas of the watershed also contribute pollutants to the water supply. Septic tanks and leach fields may be located too close to rivers for adequate protection of the water supply. Improper siting of individual systems in soils with inadequate *PERCOLATION*[7] rates can create a situation in which nearly untreated wastewater reaches a municipal source. Poor maintenance and substandard installation are also problems of septic systems that may lead to tastes and odors in community water supplies. Contamination of both surface and groundwater is often associated with individual wastewater disposal system deficiencies in relatively high density resort and vacation developments.

9.122 Industrial Wastes

Industrial discharges sometimes present significant taste and odor problems for downstream municipal water suppliers. Despite implementation of the National Pollutant Discharge Elimination System *(NPDES PERMIT*[8]*)*, 100 percent control of industrial discharges has not been achieved, nor is it likely to be achieved in the near future. While each individual discharger is required to limit concentrations of chemicals in the effluent according to levels specified by the NPDES permit, water treatment plants downstream of heavily industrialized areas may encounter problems arising from the total effects of all facilities that discharge into the supply. Furthermore, industrial wastewater treatment works are just as likely to experience process and mechanical failures as municipal treatment works are.

9.123 Chemical Spills

Chemical spills into municipal raw water sources can have detrimental effects on taste and odor quality, but the primary concern of water utility operators in such cases must be for health-related effects due to the toxicity of spilled chemicals. Most spills are the result of accidents at industrial plants, chemical storage facilities, or during transportation. Because chemical spills are unpredictable events which can lead to a large amount of contamination reaching the water treatment plant in a short time, every water utility should have an Emergency Response Plan to deal with this problem. The American Water Works Association has published a very useful handbook[9] to aid utilities in developing plans for hazardous materials spills.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 407.

9.1I What factors can cause contamination of a water supply by septic tank and leach field systems in rural areas and in resort and vacation developments?

9.1J How can industrial waste discharges cause taste and odor problems?

9.1K What are the sources of most chemical spills?

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[7] *Percolation (PURR-ko-LAY-shun). The slow passage of water through a filter medium; or, the gradual penetration of soil and rocks by water.*

[8] *NPDES Permit. National Pollution Discharge Elimination System permit is the regulatory agency document designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.*

[9] *HAZARDOUS MATERIALS SPILLS EMERGENCY HANDBOOK. Available from Data Processing Department, AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235. Order No. 20102. Price to members, $9.60; nonmembers, $12.00.*

9.124 Urban Runoff

Urban runoff contributes to tastes and odors, especially in areas where precipitation occurs only during a limited portion of the year. During dry periods, oil, grease, gasoline, and other residues accumulate on paved surfaces. When storms begin, this material is washed into the local receiving water from roadway storm drainage systems. Urban runoff also contains animal droppings from pets and fertilizers used for landscaping. Taste and odor complaints will be received from systems served by water taken downstream of this urban runoff. Usually the complaints slow down after the storm passes, and subsequent storms during the same wet season will typically not create the same degree of problem as the first storm.

9.125 Agricultural Wastes

The contribution to municipal drinking water taste and odor problems by agricultural runoff depends upon the nature and extent of farming in the watershed, precipitation patterns, and local irrigation practices. Many municipal water intake facilities have been located upstream of major agricultural areas to avoid possible contamination of the water supply by fertilizers, pesticides, and herbicides. This siting of intake facilities above heavily cultivated agricultural lands also helps protect against tastes and odors.

Grazing lands are not usually a major source of tastes and odors in municipal supplies. Significant amounts of waste material that could reach raw water sources cannot accumulate in areas where precipitation occurs regularly throughout the year. Those regions that experience limited seasons of precipitation cannot support high herd densities on grazing lands, so the annual quantity of waste material generated is less per acre. Furthermore, long dry periods allow for the drying out of animal wastes, rendering them far less offensive. When storms do occur, the dried material is generally diluted by the heavy precipitation and wet season river flows.

High density animal feeding and dairy operations can cause problems if located near surface supplies. The high concentration of animal wastes in a confined area can contribute to significant nutrient loading if runoff is allowed to drain into reservoirs or rivers during a storm. Feedlots and dairies are required to control their discharges under the NPDES program, and utilities should work with the health department and water pollution control agency to prevent serious water quality degradation due to runoff from such operations. Water systems faced with concentrated animal waste runoff into the water source need to practice careful reservoir managment and river monitoring programs in order to prevent massive taste and odor complaints.

Runoff from cultivated fields can contribute both nutrients and objectionable materials to water supplies. Modern, high-intensity farming requires the use of a wide variety of chemicals to achieve maximum crop production. Precipitation or irrigation in excess of the water-holding capacity of the field will lead to runoff which may contain residues of previously applied fertilizers, pesticides, herbicides, and the spreading agent used to apply them.

Often, it will take days for irrigation water to return to the stream or canal. During this time microbial activity may create very high concentrations of objectionable by-products. Even if these return flows represent only a small portion of the total supply, the presence of these microbial by-products in the finished water will lead to consumer complaints of tastes and odors.

9.126 Treatment Plant and Distribution System Housekeeping

Inadequate or incomplete maintenance of water treatment plants and distribution systems will result in water quality deterioration no matter how clean the raw water supply may be. Debris and sediments transported to the plant accumulate during the year in areas such as influent conduits and flocculator basins which are not equipped with sludge removal systems. Sludge removal from settling basins with pumping equipment is never 100 percent complete, and deposits will build up over a period of time. Good housekeeping in and around water treatment plants is required in order to keep the plant in a clean and sanitary condition.

Microorganisms will grow in plant debris and sludges even in the presence of a strong chlorine residual. The conditions which lead to foul, septic, musty, or other types of tastes and odors in raw water supplies may be duplicated on a smaller scale in treatment plants that are not kept clean. Periodic inspection of plant facilities is a vital part of good water treatment practice and a necessary part of an effective taste and odor prevention program.

Distribution maintenance is also an important part of taste and odor prevention. Debris which accumulates in distribution system mains and laterals provides an environment for bacterial growth. Especially susceptible are low flow zones and dead ends in which no chlorine residual is maintained. These areas allow for abundant bacterial regrowth in distribution lines which results in stagnant, septic, or foul tastes and odors. Comprehensive flushing programs should be used by utilities as part of a system water quality maintenance effort.

9.127 Household Plumbing

Sometimes a taste and odor problem is traceable directly to the consumer's plumbing system. The age and types of plumbing materials in older homes may contribute to unpleasant-tasting water. The plastic household plumbing in new housing subdivisions may require several days, or longer, before the "plastic" taste of the water disappears. Low flows in some homes, or inadequate flushing of lines and cleaning of strainers and aerators may also contribute to water quality degradation in the consumer's plumbing. However, it is poor practice to attribute widespread complaints about the taste and odor of the water to conditions in consumers' plumbing. If a large number of complaints are received from throughout the system, the chances are very good the problem is with the water supply and not the result of a large number of individual problems.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.1L Why are many municipal water intake facilities located upstream of major agricultural areas?

9.1M List some sources of agricultural wastes that may cause taste and odor problems in a water supply.

9.1N How do debris and sludge cause tastes and odors?

9.2 LOCATING TASTE AND ODOR SOURCES

9.20 Potential Sources

A wide variety of conditions that can occur in any portion of a water supply system may cause objectionable tastes and odors at the consumer's tap. When evaluating a taste and odor complaint, no segment of the system, from the raw water supply to the consumer's household plumbing, should be ignored as a potential source of the problem.

The first step in determining the cause of tastes and odors should be to locate where in the overall system the problem is originating. Once the point of origin is known, it is usually easier to determine an underlying cause and to develop plans for correcting the situation. Locating a taste and odor source is often a time-consuming process of elimination which may not yield any conclusive information. Nonetheless, the benefits of successfully identifying sources and causes of taste and odor problems are well worth the effort required.

9.21 Raw Water Sources

The most commonly reported problem faced by water facilities is the development of tastes and odors in the raw water supply (a lake, reservoir, river or canal) or in the raw water transmission facilities which deliver water from the source to the treatment plant. Any parts of the system which are used to store, transport, or regulate untreated water may provide a suitable habitat for organisms that produce objectionable tastes and odors in the drinking water.

When investigating a taste and odor problem, mentally divide the system into its major component parts based on each component's primary function such as storage, open conveyance channel, and transmission pipelines. Also consider each component's accessibility for sampling, time required for sampling, and the number of samples which can be reasonably analyzed in a timely manner. You must choose sampling locations where the water is representative of the water consumers will receive. Collecting and evaluating surface samples in a strongly stratified reservoir is useless if the water being treated is released from the lower layers.

Some examples of sampling points which would allow you to test major components of raw water supplies include: outlet works of major reservoirs and regulating basins, inlets and outlets of transmission channels and pipelines, and the plant influent upstream of any chemical additions. Analyze samples from these locations for plankton count and predominate type, total coliform and standard plate count, turbidity, pH, color, dissolved oxygen, and threshold odor number (TON).[10] Major changes in any of these water quality indicators betwen sample locations may be the result of conditions contributing to the taste and odor problem. Further analyses, if available, for such constituents as total *KJELDAHL NITROGEN,*[11] ammonia, and total organic carbon (TOC) may be useful. Resampling and inspection (if possible) of that portion of the system between sample points showing remarkably different characteristics should be conducted as soon as is possible.

When resampling and inspecting a segment of the system suspected of being the origin of the taste and odor problem, look for new or expanded residential, commercial, or industrial activity, as well as new or altered tributary streams which could contribute poor quality inflow to rivers and canals. Examine pipelines for unauthorized or unintentional *CROSS-CONNECTIONS*[12] which could provide a route for contamination to enter the supply.

9.22 Treatment Plants

Accumulated debris and sludge in treatment plant facilities will lead to taste and odor deterioration as the water is processed. Algal growth due to poor housekeeping practices is both unsightly and a potential source of tastes and odors in the finished water. Routine inspection and cleaning of all facilities are necessary elements of treatment plant operation.

Collecting samples from various points throughout the treatment plant for laboratory analysis is usually not as productive in locating taste and odor sources as it is in the raw water system. Treatment chemicals, especially chlorine and powdered activated carbon, are responsible for changes in taste and odor quality that may be occurring within the plant. Comparing taste and odor quality of raw and finished water may be useful in indicating a problem of plant origin, but there is a natural tendency to always rate treated water as of better quality than untreated. Additionally, the presence of strong, easily treated odors in the raw water may invalidate any direct comparison with finished water.

Visually inspect basin and filter walls, channels, and weirs for algal or slime (bacterial) growth. Remove any slime material and send samples to the laboratory for identification. Future growths can sometimes be prevented by regularly washing affected areas with a high pressure hose. shock treatment with chlorine through the plant or by direct application of a strong chlorine solution to points which prove to be especially difficult to keep clean.

Conduct an evaluation of plant facilities, looking for potential zones of debris accumulation in areas such as influent conduits and flocculator and settling basins. Review records of previous plant inspections and cleanings to see if some areas have a history of particularly heavy sludge buildup. Seldom is it practical to dewater a treatment plant during a taste and odor episode, but plans should be made for regular (yearly) dewatering operations to allow inspection and cleaning of suspected or potential problem facilities.

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[10] *See Chapter 11, "Laboratory Procedures," for procedures on how to perform these tests.*

[11] *Kjeldahl Nitrogen (KELL-doll). Nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl Method.*

[12] *Cross-Connection. A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.*

Windows in structures over filter galleries may allow sunlight to encourage algae and slime growths. Some plants have corrected this problem by covering the windows.

9.23 Distribution System

Conditions within a municipal water supply distribution system can significantly affect water quality received by the public. Just as adequate maintenance and housekeeping are required at the treatment plant, they are a necessary part of distribution system operation.

Taste and odor complaints originating within the distribution system are usually confined to limited areas or zones. Dead ends, low flow zones, and areas subject to wide flow variations or changes in supply source all may experience higher than normal numbers of taste and odor complaints. Records of complaints should be reviewed so such areas can be identified and preventive measures, such as more frequent flushing, can be implemented. You should recognize, however, that any change in your source water may result in taste complaints from an area, even in the absence of any bona-fide quality problems.

Cross-connections in the distribution system are potentially very hazardous and a source of taste and odor complaints. A variety of contaminants have been introduced to drinking water via cross-connections, and often the first warning the supplier has of such a condition are the complaints about a "chemical," "gasoline," or "pesticide" taste or odor in the water. Because of the potential public health hazard, complaints of this nature should receive prompt and careful attention.

Backflow prevention devices that have been improperly installed or bypassed at industrial plants have resulted in the contamination of numerous water systems. Cross-connections are also made by contractors, landscape workers, and, with disturbing frequency, municipal employees. Careless or unthinking homeowners and weekend handymen have contaminated systems by creating cross-connections. In many cases the problem was located because of the number, location, and type of taste and odor complaints received by the water utility.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.2A What are the most likely sources for the development of tastes and odors?

9.2B How do the chemicals used in a water treatment plant interfere with a search for the source of tastes and odors?

9.2C Where are the potential sources of tastes and odors within a water treatment plant?

9.2D What types of complaints would alert you to the potential of a cross-connection?

9.3 PREVENTION OF TASTES AND ODORS

9.30 Need for Prevention

AN IMPORTANT ASPECT OF ANY TASTE AND ODOR CONTROL PROGRAM IS PREVENTION. When dealing with a taste and odor problem, or for that matter any water quality problem, an ounce of prevention is worth far more than a pound of treatment. Preventing problems, at least to the extent prevention is feasible, is usually both more economical and more effective than trying to treat for tastes and odors at the plant.

9.31 Raw Water Management

As explained in Chapter 3, the role of raw water management in providing high quality water to the consumer cannot be ignored. Once a supply has deteriorated, it usually will take a change of seasons before conditions return to a desirable level. If no alternative water supplies are available to a community, deterioration of the raw water source may mean an extended period of poor quality water, or an extended period of significantly increased treatment costs, or both.

The major techniques and considerations in developing and implementing a raw water management system were described in detail in Chapter 3. If the water supply is a river rather than a reservoir, many of the treatment approaches described for reservoirs will obviously not work. However, monitoring rivers for changing raw water quality and for sources of pollution which may adversely affect a community water supply are both activities which should be conducted as part of a river management strategy.

9.32 Plant Maintenance

Settled sludges and other debris which may be transported to the plant by the raw water need to be removed on a regular basis. These materials provide local environments in which organisms grow and multiply. If left for an extended time, these areas will become septic and impart a foul taste and odor to the water. Depending upon the type of material, the quality of the water, and the source and nature of debris which accumulates, rotten egg (hydrogen sulfide), bitter, musty, earthy, swampy, fishy, or grassy tastes and odors will result.

Many treatment plants schedule annual shutdowns to allow inspection and thorough cleaning of all facilities, especially those which are normally submerged. Other, generally larger, plants are designed so that one part of the plant may be taken out of service for inspection and cleaning while another is still operating. This routine cleaning is commonly done during the winter months when flows are lower and full plant capacity is not needed to meet the community's water demands.

Another aspect of plant maintenance that relates to the prevention of tastes and odor episodes at the consumer's tap is the use of on-going programs that will assure that those facilities which may be required to treat a taste and odor are functioning properly at all times. No matter how well managed a surface supply is, or how well the treatment plant is maintained in sanitary condition, surface water conditions will change from time to time and will result in water quality deterioration. If facilities such as powdered activated carbon feed systems are not in functioning condition when they are needed, they are of no value. Periodic inspection and testing of such equipment is necessary to assure that it will work properly when needed and that emergency repairs will not have to be made just at the time when the equipment is needed most.

9.33 Distribution System Maintenance[13]

The quality of water delivered to the consumer is the result of both adequate treatment and maintenance of that quality through the distribution system. Without procedures to assure that the distribution system is capable of maintaining water quality, the consumer will not receive high quality water no matter how well the treatment plant is operated.

Many systems have specified stations within the distribution system which are routinely flushed throughout the year to prevent the development of problems. The locations of these stations and the frequency at which they are flushed is determined from records of complaints and water quality tests. This indicates the importance of good recordkeeping as a tool for water quality management. Records can be used to evaluate the effectiveness of these spot flushings, the frequency of flushing, and the need to add or rotate stations during the year.

Annual flushing programs also play a part in maintenance of water quality in the distribution system. Again, records should be used to guide the program. In many cases it is both impossible and unnecessary to flush all parts of the system every year. Review of records may indicate that most zones of a system only need complete flushing every three to five years. Such a program, in combination with routine flushing of problem zones, is more economical and as effective as complete flushing every year.

Flushing alone does not provide an adequate level of protection against the development of tastes and odors in a municipal distribution system. Routine collection of samples for taste and odor tests, especially in systems subject to seasonal outbreaks, can provide an early warning of quality deterioration. These samples should be collected when coliform bacteria samples in the distribution system are collected. This is especially important since tests at the treatment plant may not accurately indicate water quality in the distribution system. The higher chlorine residual and shorter chlorine contact time at the plant tend to give the water at the plant better taste and odor properties than may be encountered in the distribution system.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.3A What happens when settled sludges and other debris are allowed to accumulate in the bottoms of channels and tanks in a water treatment plant?

9.3B When are portions of water treatment plants usually taken out of service for inspection and cleaning while the remainder of the plant continues to operate?

9.3C Why should taste and odor treatment equipment be capable of operating properly at all times?

End of Lesson 1 of 3 Lessons
on
TASTE and ODOR CONTROL

DISCUSSION AND REVIEW QUESTIONS

Chapter 9. TASTE AND ODOR CONTROL

(Lesson 1 of 3 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should answer before continuing. The purpose of these questions is to indicate to you how well you understand the material in this lesson. Write the answers to these questions in your notebook before continuing.

1. Taste and odor problems are likely to have what types of effects on a water utility when they occur?
2. What will consumers do if they are supplied water with an objectionable taste or odor?
3. How can the use of copper sulfate in a reservoir cause a taste and odor problem?
4. How can oxygen-poor conditions during the night produce tastes and odors in water?
5. How does pollution cause tastes and odors?
6. How can high levels of natural runoff lead to tastes and odors?
7. What factors influence the contribution of agricultural runoff to taste and odor problems?
8. How can tastes and odors develop within a water treatment plant?
9. What is the first step in determining the cause of a taste and odor problem?
10. How would you attempt to find the location of the source of a taste and odor problem?
11. Where in a distribution system would you look for the sources of tastes and odors?
12. How is the frequency of flushing mains in a water distribution system determined?

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[13] *See WATER SUPPLY SYSTEM OPERATION in this series of manuals for additional information on the operation and maintenance of distribution systems.*

CHAPTER 9. TASTE AND ODOR CONTROL

(Lesson 2 of 3 Lessons)

9.4 TASTE AND ODOR TREATMENT

9.40 Methods of Treatment

Because objectionable tastes and odors are the result of so many different causes and because each water system has its own unique characteristics, no single treatment will be applicable to all taste and odor problems. Each utility must develop procedures to deal with its problems on an individual basis. Successful problem solving depends on understanding some of the important general properties of the most commonly used taste and odor treatment methods.

Taste and odor treatment methods can be divided into two broad categories: removal and destruction. Often both techniques are used. Multiple treatments, perhaps three or four, may be necessary to produce water of acceptable quality.

Removal techniques include optimum coagulation/flocculation/sedimentation, *DEGASIFICATION,*[14] and adsorption. Destruction of tastes and odors is accomplished by various methods of oxidation. The following sections describe the commonly used methods of treatment.

9.41 Improved Coagulation/Flocculation/Sedimentation

Depending upon the type of taste and odor, and on the raw water quality, improving sedimentation and associated processes may produce a better tasting water. This is especially true if the taste and odor quality has deteriorated during a period when changes in raw water turbidity, color, or pH have suddenly occurred. Such changes might occur during spring or fall turnover of a lake or reservoir, or during high flows in rivers and canals due to storm runoff. Increases in color and pH may also be the results of an algal bloom, in which case the number of algae in the raw water can be expected to show a large increase.

As was discussed in Chapter 4, turbidity, color, and pH can all have a significant effect on coagulation. In addition to removing suspended particulates, inorganic salts such as alum have been shown to reduce the organic content of water, though turbidity and organic removal may occur at different dosages. In order to determine if increased coagulant dosages will reduce objectionable tastes and odors, the standard jar test procedure can be used followed by tests for both settled water turbidity and threshold odor number.

In cases where tastes and odors increase because of increased algal populations, successful attempts to improve coagulation and sedimentation may produce longer filter runs. Removal of the algae in the sedimentation basin rather than by filtration will allow longer filter runs. In plants where chlorine is applied to the water just upstream of the filters, removal of the organisms by sedimentation may improve taste and odor quality by reducing the action of chlorine on the algal cells that would otherwise be trapped on the filters. The reaction of chlorine on algal cells results in the release of objectionable cellular materials into the water. Further reaction between these cellular products and chlorine may produce *CHLORORGANIC*[15] compounds which impart an even more objectionable taste to the water.

The degree of success that may be obtained by improving coagulation might be difficult to assess, especially if the problem is of short duration. However, if it solves the problem, improving coagulation may be the simplest and most economical approach available to the water treatment plant operator for controlling tastes and odors.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.4A List the two broad categories of taste and odor treatment methods.

9.4B How can tastes and odors caused by algae be removed most economically in a water treatment plant?

9.4C How does the use of chlorine influence taste and odors when water contains algae?

9.42 Aeration Processes and Systems

9.420 Description of Processes

Aeration is the process of mixing air and water together through various means. *THE USE OF AERATION IN TASTE AND ODOR CONTROL IS EFFECTIVE ONLY IN REMOVING GASES AND ORGANIC COMPOUNDS WHICH ARE RELATIVELY VOLATILE.*[16] In general, volatile compounds will be noticed as objectionable odors while less volatile compounds are more often associated with objectionable tastes. Aeration is somewhat more successful in treating an odor problem than in treating water with objectional tastes.

Removal of odor-producing substances that are volatile, as well as other volatile compounds, is known as degasification. Because the compounds being removed exist at a lower concentration in the air than in the water, they will tend to leave the water and move into the air. The more air that is circulated through the water, the greater the amount of objectionable volatile compounds that will be removed from the water. By increasing the aeration rates, the concentration of the objectionable compound present in the water may be reduced to a level at which it no longer causes a problem. As stated above, this process only works if the compound is sufficiently volatile.

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[14] *Degasification (dee-GAS-if-uh-KAY-shun). A water treatment process which removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.*

[15] *Chlororganic (chlor-or-GAN-nick). Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.*

[16] *Volatile (VOL-uh-tull). A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.*

Aeration can also destroy some compounds by *OXIDATION.*[17] While this can be quite effective for treating *REDUCED*[18] inorganic compounds such as ferrous iron or manganous manganese, it usually is not very effective in the treatment of tastes and odors resulting from the presence of volatile organic compounds. Aeration normally does not provide enough oxidation to attack the taste- and odor-producing organics.

Aeration systems are designed to operate in one of two ways: some systems pass air through the water; other systems pass the water through the air. That is to say, in one type of system air is pumped into the flow of water by some type of air pump, while in the other the water is distributed through the air by nozzles or cascades. A process called air stripping combines elements of both techniques by flowing water over columns of support medium while air is introduced into the water through openings at many points within the support system.

When chemicals are used to treat taste and odor problems, additional treatment by aeration may reduce the chemical dosage needed. The additional benefit to improve taste and odor quality from aeration is usually a minor consideration.

9.421 Air Blowers

Air blowers are basically compressors which supply air under pressure to the water. Large volumes of air are pumped into the water, generally through diffusers along the bottom of a trough or channel, and the air is allowed to rise to the surface. Along the way gases are exchanged between the air bubbles and the surrounding water.

Efficient degasification requires bubbles of very small size to achieve maximum gas transfer. The small bubble size requires that air diffuser orifices be very small. For a specific volume of air, the small orifice size means that high delivery pressures must be supplied by the compressor. In order to make air blowers effective as direct aeration units, a large unit may be needed.

Air blowers can serve as very effective mixing devices, however, since small bubble size is not an important consideration for mixing. Significant turbulence can be produced by air diffusers located on the bottom of a channel. This turbulence can be used to achieve some degree of degasification by exchanging water between the bottom of the channel and the water surface where some volatile compounds escape to the atmosphere. For odor problems caused by highly volatile substances such as hydrogen sulfide, this type of aerator may provide adequate control. However, general application of air blowers for taste and odor control is usually not a very effective technique and it is not widely used today.

9.422 Cascades and Spray Aerators

Cascades and spray aerators are termed waterfall devices since they aerate water in a manner similar to waterfalls in rivers. These systems pass the water through the air, as opposed to blower devices which introduce air into the water. Both systems are limited to the removal of readily oxidizable or highly volatile compounds just as are air blowers.

Cascade systems are essentially a series of small waterfalls. The water flows down over a series of tiers which may have some type of medium to increase turbulence and improve aeration efficiency. A simple cascade system design consists of a series of concrete steps over which the water flows. When the water reaches the bottom, it flows into a collection basin and is routed on through the treatment plant. A simplified diagram of a cascade system is shown in Figure 9.2.

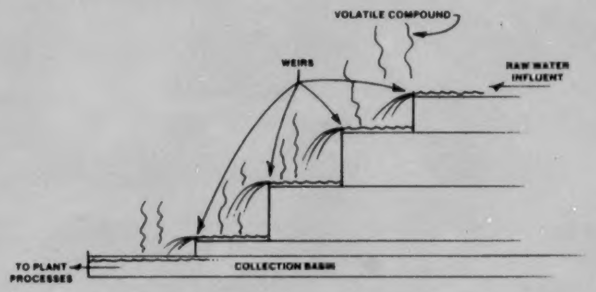

Fig. 9.2 Simple cascade aerator system

Spray aerators, as the name implies, spray water through the air to achieve aeration. In order to be effective, the water must be dispersed into fine droplets. Again, efficiency depends on extensive exposure of the water to air for gas transfer. The number of spray nozzles necessary will depend upon plant flow rates, available head, and space limitations. Evaporation losses are a disadvantage of these systems.

Waterfall devices can provide a visual appeal similar to public fountains which they resemble. However, they may encourage biological growths which may contribute to taste and odor problems. Continuous copper sulfate treatment has been applied at some facilities using these open-water systems to control such growth.

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[17] *Oxidation (ox-uh-DAY-shun). Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.*

[18] *Reduction (re-DUCK-shun). Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds.*

9.423 Air Stripping (Figure 9.3)

Air stripping is a process which combines elements of both air blowers and waterfall devices to achieve aeration. While not commonly used at conventional water treatment plants, this method may find future application at facilities which must treat both tastes and odors and other trace organic contamination in drinking water supplies.

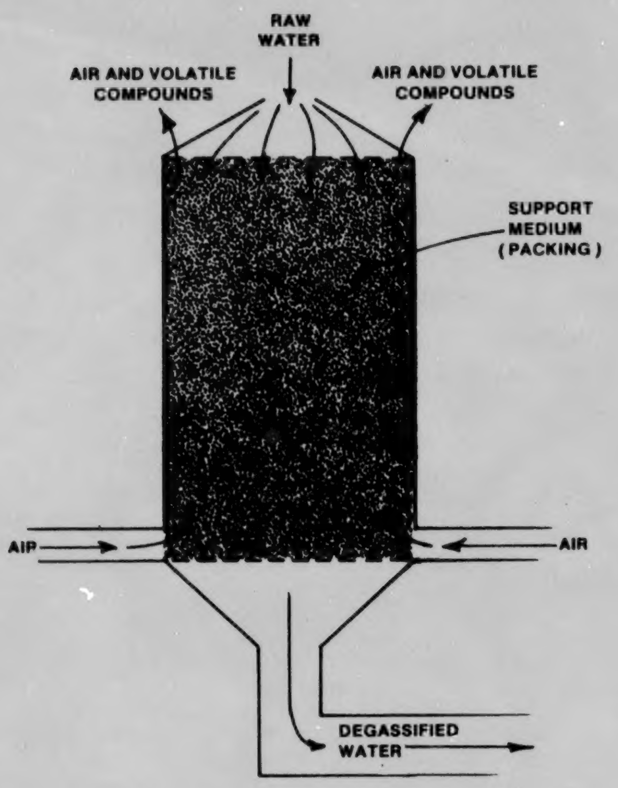

Fig. 9.3 Updraft air stripping tower

Air stripping is achieved by flowing water over a support medium, or packing, contained in a tower while pumping air through the packing in the opposite direction. This arrangement of counter-current (opposite direction) flow provides increased aeration, and therefore improved removal of volatile substances. Water flow is downward through the support medium.

As with other aeration devices, air stripping will only be effective in removing compounds which are highly volatile.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.4D Aeration is best suited for treating what type of taste and odor problems?

9.4E What are the two basic ways that aeration systems can be designed?

9.43 Oxidative Processes

9.430 Types of Processes

Chemical oxidation is a destructive technique used to control tastes and odors. By application of a strong oxidant, objectionable compounds are chemically modified or broken down into less objectionable by-products. The method is perhaps the most common taste and odor control process because of the widespread use of chlorine, a strong oxidant, for disinfection in water treatment.

In addition to chlorine, there ar three other chemicals which deserve some attention as oxidants for the removal of taste and odor compounds. These are potassium permanganate ($KMnO_4$), ozone (O_3), and chlorine dioxide (ClO_2). All are receiving increased attention in the water industry as alternatives to chlorine at plants that must deal with levels of trihalomethanes in excess of the maximum contaminant level.

9.431 Chlorine

Chlorine has been used in water treatment in this country for most of this century, primarily because it is such an effective and relatively inexpensive disinfectant. Because facilities for chlorination are already in place at most water treatment plants, adjustments of chlorine dosages are often used to improve taste and odor quality. In normal cases, where chlorine is applied in a disinfection dosage range, it will often be necessary to increase the normal chlorine dosage to obtain optimal taste and odor treatment.

Many odors in raw water are readily treated by the use of chlorine. Easily detectable odors such as fishy, grassy, or flowery odors can often be decreased significantly with normal chlorination dosages or slight overdoses. In plants where prechlorination is practiced, it may not even be necessary to change routine treatment to produce a high quality water. In cases where prechlorination is not routinely applied, some tastes and odors may be eliminated by adding chlorine early in the treatment processes. The success of chlorination as a taste and odor treatment will depend upon the type of odor, the seriousness of the problem, the dose applied, and the contact time between chlorine and the water prior to delivery to the consumer.

Increased chlorine doses, including *SUPERCHLORINATION*,[19] have been used successfully to treat some difficult taste and odor problems. Higher doses are most beneficial when applied to the plant influent. This allows the greatest contact time and the use of higher doses without adversely affecting consumers located near the treatment plant. Some plants routinely use superchlorination as the initial step in taste and odor control. This process, in which chlorine doses far in excess of that required to meet the chlorine demand are used, increases the likelihood of adequate oxidation of the target compound. Superchlorination is followed by dechlorination as part of the treatment for tastes and odors. The use of high chlorine doses in pretreatment permits later use of powdered or granular activated carbon to remove excess chlorine.

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[19] *Superchlorination (SUE-per-KLOR-uh-NAY-shun). Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.*

Despite widespread use and success, chlorine may sometimes be the wrong choice of treatment for a taste and odor problem. Some compounds may become more objectionable after chlorination than before treatment. This is usually the result of incomplete oxidation or substitution of chlorine atoms onto a taste- and odor-causing molecule. For example, chlorination of water containing *PHENOLIC COMPOUNDS*[20] (phenols) often results in the production of highly objectionable *CHLOROPHENOLIC*[21] compounds. Chlorophenolic compounds cause noticeable tastes and odors even in concentrations 40 to 200 times *LESS* than the original phenol. In such cases, further laboratory testing is needed to determine if the chlorine dosage should be increased or decreased. The standard jar test procedure followed by tests for odor quality can be used to indicate the direction to proceed (usually the dosage can be reduced).

9.432 Potassium Permanganate

Potassium permanganate ($KMnO_4$) has been used for a number of years in both water and wastewater treatment. Permanganate is a strong chemical oxidizer which can be used to destroy many organic compounds of both natural and man-made origin present in water supplies. Permanganate is also used to oxidize iron, manganese, and sulfide compounds and is often used in conjunction with aeration for the control of these and other taste- and odor-producing substances.

A critical aspect of potassium permanganate treatment is color control. This material produces an intense purple color when mixed with water. As the permanganate ion is reduced during its reaction with compounds that it oxidizes, the color changes from purple to yellow or brown. The final product formed is manganese dioxide (MnO_2), an insoluble precipitate that can be removed by sedimentation and filtration. All of the $KMnO_4$ applied must be converted to the MnO_2 form prior to filtration. If the purple-to-pink color reaches the filters, it will pass into the clearwell or distribution system. This may result in the consumer finding pink tap water, or the reaction may continue in the system and the same conditions as exist with naturally occurring manganese will result (staining of plumbing fixtures).

In order to prevent this situation it is necessary to determine the maximum $KMnO_4$ dose that can be safely applied in the plant *BEFORE* starting a permanganate treatment program. To do this, measure the time required for the last trace of pink to disappear from a series of jar tests. Mix the test samples for a time similar to the detention time in the sedimentation basin. You should allow for a margin of error in this determination; for example use a time equal to one-half to three-quarters of the actual detention time when running these laboratory trials. In actual plant operation, many operators control permanganate dose by adjusting the feed rate so that the pink or purple color is visible only to a specific point in the basin. This involves a simple process of observation, and is important when treating water that exhibits major fluctuations in permanganate demand. At night, however, visual observations are more difficult and you may want to use a reduced daytime dosage. Some plants use on-line permanganate analyzers to assist with permanganate dose control (Figure 9.4).

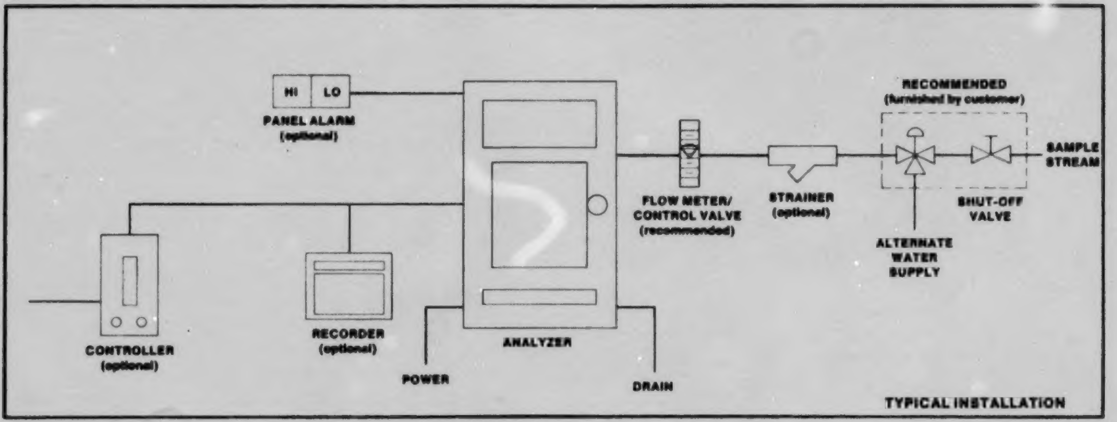

Fig. 9.4 Permanganate on-line analyzer

(Permission of the HACH company)

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[20] *Phenolic Compounds (FEE-noll-LICK). Organic compounds that are derivatives of benzene.*

[21] *Chlorophenolic (klor-o-FEE-NO-lick). Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.*

If raw water is transported to the plant through a pipeline or canal, application of the potassium permanganate at the inlet is a desirable practice. This allows an extended contact time for the reaction to produce manganese dioxide and allows somewhat higher permanganate doses (if required for adequate taste and odor control). This also provides the opportunity for monitoring the plant influent for color or soluble manganese, giving the operator an early warning system for a permanganate overdose.

If a permanganate overdose does occur, powdered activated carbon can be used to control the problem until the permanganate dosage rate has been adjusted to the correct level. In some extreme cases it may be necessary to increase the pH of the water for a short time to increase the rate at which the manganese is precipitated. While it is better to maintain a permanganate dose which will not cause a problem, or to respond by the addition of powdered activated carbon, pH adjustment to precipitate manganese in the clearwell is still preferable to manganese deposition in the distribution system or in the consumers' sinks.

Experience at various water treatment plants has shown that typical permanganate application rates for taste and odor control are about 0.3 to 0.5 mg/*L*, though the range reported is from 0.1 to 5 mg/*L*. The cost of this comparatively expensive chemical must be considered when you are trying to set cost-effective dosage ranges.

At one water treatment plant, $KMnO_4$ in the range of 0.3 to 0.5 mg/*L* has been applied at a river intake structure approximately 13 miles upstream from the plant for taste and odor control. Permanganate treatment has resulted in a 65 percent reduction in complaints at this facility which has a seasonal problem with a musty-earthy taste in the water. Detention time between $KMnO_4$ application and the treatment plant is normally more than six hours. This allows plenty of time for complete conversion of the permanganate to the manganese dioxide form before the water enters the sedimentation basin.

9.433 Handling of Potassium Permanganate

Potassium permanganate is a dry crystalline product that is best delivered from a dry feeder into a special mixer immediately prior to application. A portable feeder is shown in Figure 9.5. Permanganate storage facilities must be dry and well ventilated as moisture in the atmosphere can cause caking of the material. This will cause the feeder to clog and prevent accurate delivery of the permanganate.

Ventilation in a permanganate feeding and storage area is important for both operator safety and equipment protection. Potassium permanganate will produce a very fine dust during loading and handling. This dust is irritating to the eyes, mucous membranes, and even to the skin of some sensitive individuals. When handling permanganate, wear goggles, a dust mask and gloves. Protective outer clothing (such as rain gear) should also be worn to prevent discoloration[22] of skin and clothes.

Adequate dust control and ventilation is also important for equipment protection. Permanganate and moisture create a very corrosive mixture which will attack metal, including electrical connections. By ventilating the area during loading and maintaining as dry an environment as is possible, the service life and reliability of permanganate feed equipment will be improved.

Never store permanganate in the same area where activated carbon is stored because they are both highly flammable.

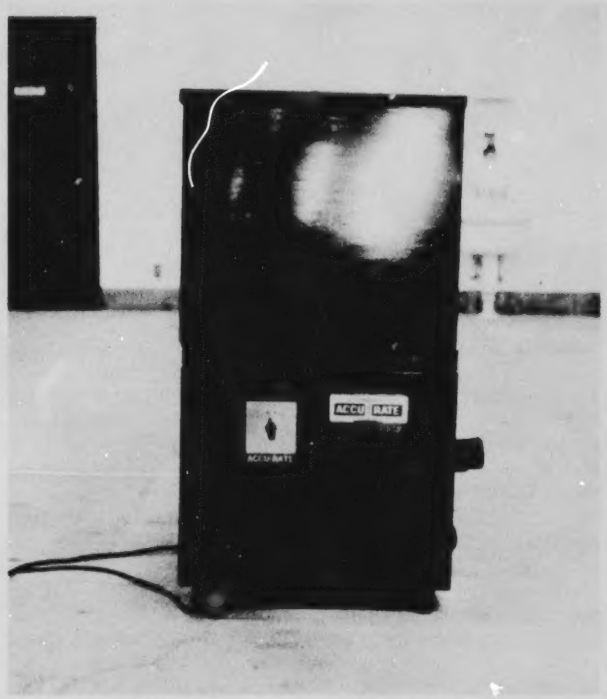

Fig. 9.5 Portable $KMnO_4$ dry feeder used at intake structure

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.4F What types of odors can often be decreased significantly by chlorination?

9.4G Under what circumstances might the use of chlorine be the wrong treatment for a taste and odor problem?

9.4H How would you respond to a permanganate overdose?

9.4I Why must permanganate storage facilities be dry and well ventilated?

9.4J Why is adequate permanganate dust control and ventilation important for equipment protection?

9.434 Ozone

Ozone (O_3) is an unstable form of oxygen that is an extremely powerful oxidant. The compound in its pure state is a bluish gas which has a pungent penetrating odor; it can sometimes be detected around large electric motors. Ozone is produced by passing dry air, or oxygen, through a high energy ionizing unit known as an ozonator. Because it is unstable, ozone must be generated on-site for use in water treatment.

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[22] *To remove permanganate stains from the skin, a strong solution of sulfite compound (sodium sulfite/meta-bisulfite) works very well.*

Ozone is a stronger oxidant than chlorine and, therefore, destroys a wider range of organic compounds. Ozone has a distinct advantage over chlorine treatment for taste and odor in that objectionable by-products of the reaction do not normally form. This is of particular advantage when the taste and odor is of industrial origin, since the combination of chlorine and some industrial pollutants can lead to more intense tastes and odors than caused by the original compounds.

Ozone has received much attention in recent years as an agent for oxidizing organic contaminants present in some water supplies and as a means of disinfecting water without producing trihalomethanes. While not commonly used in this country, ozone treatment has been applied extensively in water treatment in Europe.

Production of ozone on-site for water treatment requires specialized equipment. The basic elements of an *OZONATION*[23] system include a source of dry air or oxygen, a condenser and dryer to remove traces of moisture in the feed gas, the ozonator, an enclosed contactor unit where the ozone is mixed with the water, and a means for venting or recycling waste gas from the contactor. These units are shown schematically (skee-MAT-ick-lee) in Figure 9.6.

Because of the specialized equipment requirements and costs, laboratory and pilot-scale testing of the effectiveness of ozonation as a taste and odor control process or for elimination of THMs should be conducted before full-scale installation. Utilities considering purchase of an ozonation system should contact manufacturers or consulting engineering firms for assistance in the evaluation and design of ozone systems.

9.435 Chlorine Dioxide (Also see Section 7.24, "Chlorine Dioxide")

Chlorine dioxide (ClO_2) is another chemical oxidant that has received increased attention in recent years as a result of concern about the formation of trihalomethanes in water following chlorination. Chlorine dioxide, like ozone, is a strongly oxidizing, unstable compound. Chlorine dioxide is formed by reacting sodium chlorite and chlorine in a special ClO_2 generator. Because it is unstable, it too must be generated on-site at the time it is to be applied to the treatment process. Chlorine dioxide has been used to treat tastes and odors caused by industrial pollution, especially in cases where chlorine has intensified the problem.

While chlorine dioxide has been reported to reduce taste and odor complaints in some cases, other agencies have experienced more severe problems following ClO_2 treatment. The Louisville, Kentucky, Water Company experienced sharp increases in taste and odor complaints during initial trials with ClO_2 as a method for lowering distribution system trihalomethane (THM) levels. The problem was resolved by using ClO_2 at the plant influent followed by combined chlorine treatment of water flowing into the clearwell.

A further consideration in the use of chlorine dioxide is the formation of unwanted chlorite and chlorate ions. There is concern over the possible health-related effects of these reaction products. Limitations for allowable concentrations have been imposed which may prevent the use of chlorine dioxide at doses adequate to control tastes and odors.

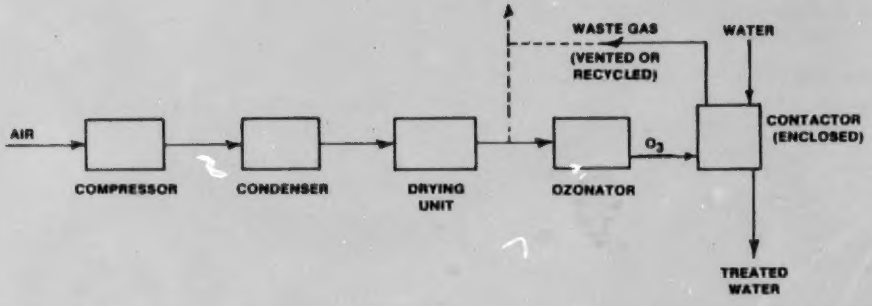

Fig. 9.6 Processes in ozonation

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[23] *Ozonation (O-zoe-NAY-shun). The application of ozone to water for disinfection or for taste and odor control.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.4K Why should laboratory and pilot-scale testing of the effectiveness of ozonation as a taste and odor control process be conducted *BEFORE* full-scale installation?

9.4L Why must chlorine dioxide be generated on-site?

9.4M What types of taste- and odor-producing wastes have been treated successfully by using chlorine dioxide?

End of Lesson 2 of 3 Lessons on TASTE and ODOR CONTROL

DISCUSSION AND REVIEW QUESTIONS

Chapter 9. TASTE AND ODOR CONTROL

(Lesson 2 of 3 Lessons)

Write the answers to these questions in your notebook before continuing. The question numbering continues from Lesson 1.

13. How would you use jar tests in an attempt to solve a taste and odor problem?
14. What problems may be created by the use of cascades and spray aerators and how are these problems solved?
15. How would you prevent color from potassium permanganate reaching a consumer's tap?
16. What safety precautions should you take when handling potassium permanganate?
17. What is the major advantage of ozone over chlorine treatment for taste and odor control?

Chapter 9. TASTE AND ODOR CONTROL

(Lesson 3 of 3 Lessons)

9.44 Adsorption[24] Processes

9.440 Types of Processes

Adsorption is the process of removing materials from water by adding a material to the water to which the taste- and odor-producing compounds will attach themselves. In water treatment this is accomplished in one of two ways: (1) the addition of powdered activated carbon (PAC) to the treatment process, usually at the influent; or (2) the use of granular activated carbon (GAC) as a filter medium. The material being removed by adsorption is known as the adsorbate, and the material responsible for the removal is known as the adsorbent.

The primary adsorbents for water treatment are the two types of activated carbon mentioned above: powdered and granular. These materials are activated by a process involving high temperature and high-pressure steam treatment. The original source of the carbon may be wood, coal, coconut shells, or even bones. The purpose of the activation process is to significantly increase the surface area of the particles so that more adsorption can take place per pound of carbon. The surface area is increased during activation by the formation of holes and crevices in the carbon resulting in particles which have a very porous structure. The surface of activated carbon may range from 400 to 2000 square meters per gram (2 to 9 million square feet per pound). This large surface area is responsible for the high degree of effectiveness that can be achieved with this remarkable substance.

An important consideration in evaluating carbon treatment is that the nature of the porous structure will exert a significant effect on the success of the treatment. If the pores of the carbon are too small, the compounds that are being treated will not be able to enter the structure and only a small portion of the available surface area will be used. Activation processes produce carbons with different surface areas. Since adsorption is a surface phenomenon, carbons with greater surface area generally provide greater adsorptive capacity.

Activated carbons are typically rated on the basis of a "phenol number" or an "iodine number." The higher the value, the greater the adsorption capacity of the carbon for phenol or iodine. This is an excellent approach for evaluating the effectiveness of a carbon for removal of phenol or iodine, but there may be no direct relationship between the compounds causing taste and odor and the phenol or iodine of the test. Only by testing various carbons for effective removal of the objectionable taste or odor can a good comparison be made for a particular application.

9.441 Powdered Activated Carbon

9.4410 Description of process. Powdered activated carbon (PAC) adsorption is the most common technique used specifically for taste and odor control at water treatment plants in this country. This widespread use is due largely to its non-specific action over a broad range of taste- and odor-causing compounds. While useful in treating many taste and odor problems, PAC treatment does have limitations, and its effectiveness and required dose rate vary widely from plant to plant.

Powdered activated carbon may be applied to the water at any point in the process prior to filtration. Because carbon must contact the material to be removed in order for adsorption to occur, it is advantageous to apply PAC at plant mixing facilities. Powdered activated carbon is often less effective at removing compounds after chlorination, so application upstream of chlorine treatment is desirable. Chlorine will react with carbon and neutralize the effects of both. From an economic standpoint, therefore, it is not good practice to apply chlorine and PAC near the same location.

Powdered activated carbon is often applied at the plant flash mixer. This location provides high rate initial mixing and the greatest contact time through the plant. Again, both thorough mixing and long contact time improve the effectiveness of PAC. Another common location for PAC application is the filter influent. While contact time and mixing are drastically reduced compared to flash-mix application, this method assures that all of the water passes through a PAC layer prior to release into the distribution system. This procedure is sometimes used with $KMnO_4$ treatment to prevent colored water problems in the distribution system.

When PAC is used, dosages may range from 1 to 15 mg/*L*. Some reports in the literature have indicated that as much as 100 mg/*L* have been required to adequately treat some serious taste and odor problems. At very high doses, treatment costs become prohibitive, and consideration of granular activated carbon treatment in its own contactor (filter) is warranted.

9.4411 Powdered activated carbon feed systems. Powdered activated carbon feed systems may be either dry-type feeders or slurry feeders. At small-scale applications the dry-type feed system may be satisfactory, especially if it is only used for short term, occasional incidents. More frequent PAC treatment requirements, or larger applications are usually best accomplished with *SLURRY*[26] systems.

Carbon slurry tanks require continuous mixing to prevent settling and caking of the carbon. Typical installations provide a vertical bi-level (two-blade) paddle mixer and vertical wall-mounted baffles for mixing. One mixer blade is located near the bottom of the tank and the other is situated about mid-depth. Carbon tanks should have drain sumps, but the suction side of the carbon intake should not extend into the sump. The reason is that during loading operations all types of foreign material can find its way into the tank through the dump chute or in the material itself. At one water treatment plant carbon tanks have been found to contain sand, wood chips, plastic and paper after having been thoroughly cleaned prior to reloading.

Because PAC has a tendency to cake, even when continuously mixed, and because of the variety of miscellaneous

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[24] Adsorption (add-SORP-shun). The collection of a gas, liquid, or dissolved substance on the surface or INTERFACE[25] zone of another material.

[25] Interface. The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

[26] Slurry (SLUR-e). A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

materials found in carbon tanks, standard practice at some plants is to clean each carbon slurry tank prior to receipt of a new shipment of carbon. The cleaning procedure allows a visual inspection of the tank, including the mixer blades and baffles.

Powdered activated carbon is a somewhat hydrophobic (HI-dro-FOE-bick) material and does not mix readily with water. When carbon is being loaded into slurry tanks, an overhead spray system in the tank should be used. This spray accomplishes some degree of dust control as well as an initial wetting of the carbon. To load a PAC tank, fill it about one-quarter to one-third full of water before starting, and operate the mixers during loading.

Proceed slowly enough to allow complete mixing and wetting of the carbon as it is introduced into the tank. If the mixing capability of the tank is exceeded, the PAC will form a cake on the surface of the water. The caked material will prevent additional carbon from being properly mixed, and a thick, tough layer of floating carbon will form in the tank. Once formed, caked PAC is difficult to disperse into a useful slurry. If PAC does not mix rapidly during loading, stop the operation, check mixers and sprayers, and break up any cake that has formed. The cake can be broken up using breaker bars (crow bars) or wooden paddles (2x4s). If all equipment is operating properly, the loading rate must be reduced to the level at which the system can adequately mix the carbon into a slurry.

Figures 9.7, 9.8 and 9.9 show typical PAC feeders and storage tanks.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 408.

9.4N What two forms of activated carbon are used in water treatment?

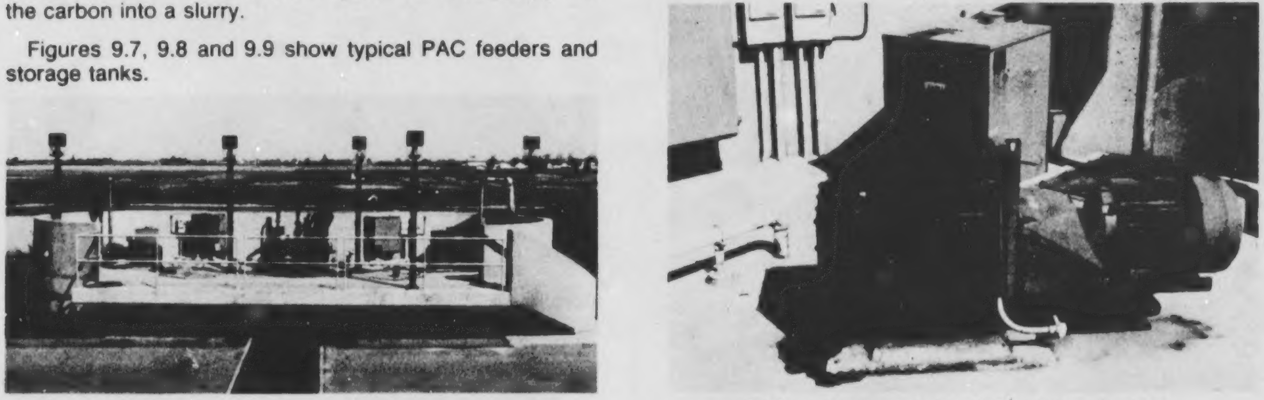
9.4O What terms are used to describe the adsorptive capacities or ratings of activated carbons?

9.4P Why should powdered activated carbon be applied at the plant flash-mixing facilities?

9.4Q What would you do if a caked layer of carbon starts to form on the surface of the water in the slurry tank?

9.4412 Powdered activated carbon dose determination. The appropriate dose of PAC for any particular problem will vary depending upon the nature of the problem, the concentration of the material to be removed, the mixing available, the contact time, and the location of application points. Jar tests should be used to determine the necessary PAC doses required to treat the specific taste and odor problem that exists. By simulating mixing speeds and detention times of the various locations at which the carbon might be applied, and by varying the doses of carbon, the jar test can be used to indicate the most effective range of carbon treatment.

Accurate determination is difficult to make of the threshold odor number (TON) of a sample when several jar tests are run all at once. A person's sense of smell becomes rapidly fatigued and after just two or three TON tests individuals tend to become desensitized to the odors present. Because only a limited number of operators are usually available for odor testing, a single operator will often have to do all of the tests. Misleading results may be obtained if more than a few TON determinations are made by the same person in a short time. Also, if the air around the plant contains the odor of concern, none of the people at the plant site will be able to perform the TON test. When your nose smells the same odor for a long time, eventually you will be unable to detect that odor due to *OLFACTORY FATIGUE.*[27]



Feed pumps are located on deck above underground PAC slurry tanks

PAC tank mixer motor with right-angle drive

Fig. 9.7 Powdered activated carbon (PAC) feeders and storage tanks

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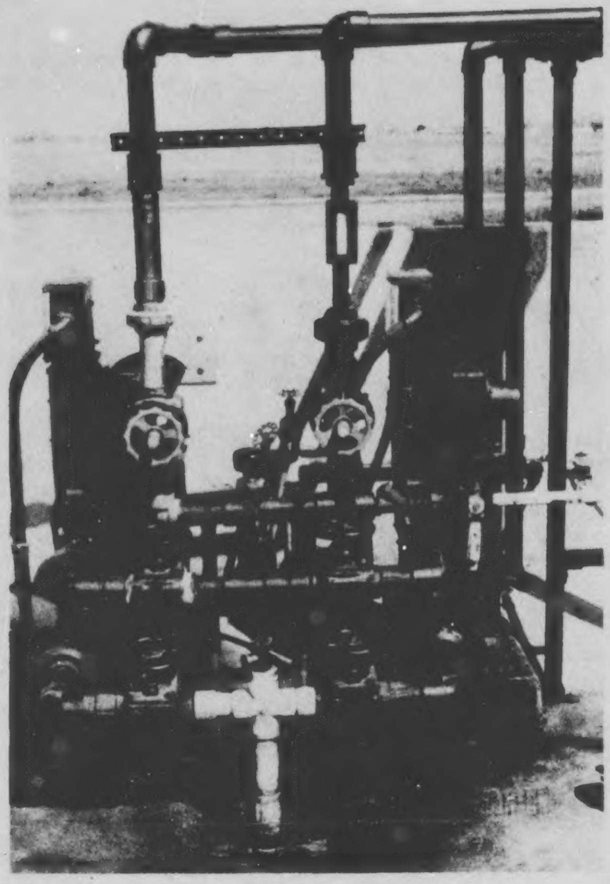
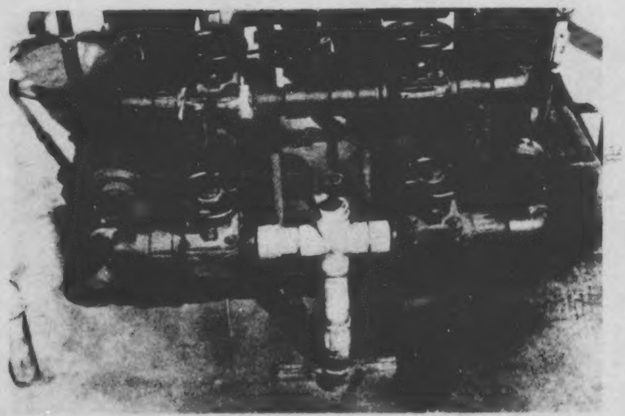
[27] ***Olfactory Fatigue** (ol-FAK-tore-ee). A condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor.*

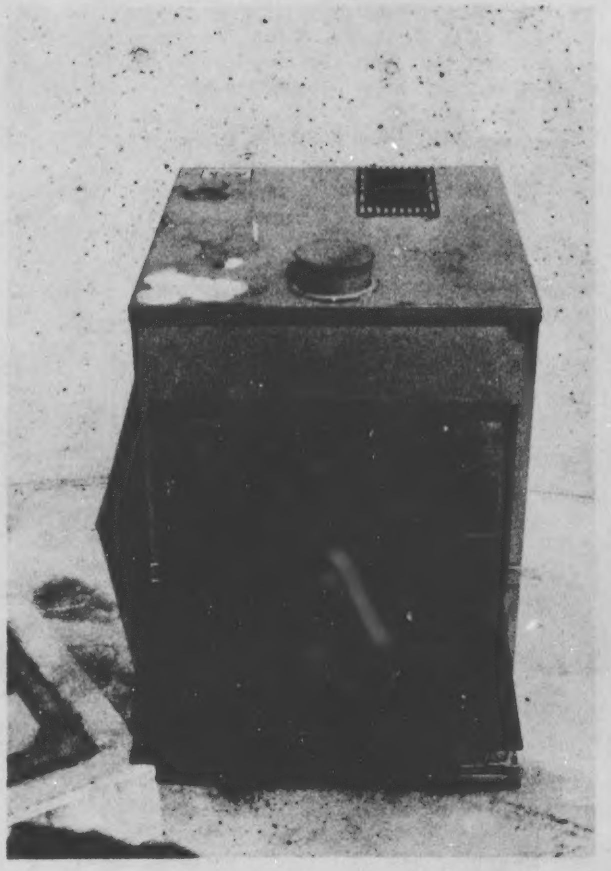


PAC feed pumps. Piping (PVC) in front is slurry suction line from tanks

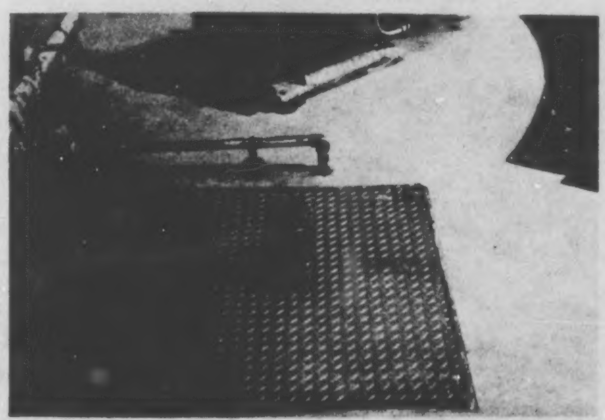


Close-up of slurry suction line. Hose bib allows back flushing of suction line in case of plugging

Fig. 9.8 Powdered activated carbon feeders and storage tanks



Dust collector for bagged carbon loading. Carbon is loaded through lower unit while dust collector is in upper unit.



Four-inch "quick-connect" fitting to allow bulk loading of PAC from truck.

Fig. 9.9 Powdered activated carbon feeders and storage tanks

A more practical approach, especially during initial testing, is to compare the *RELATIVE* (subjective) odor of jars dosed at different PAC levels. (This same method can be applied to the preliminary evaluation of all tastes and odor treatments.) After mixing for an appropriate time, collect undiluted samples from each jar. Starting with the sample from the jar test treated at the highest level, test (smell) each sample in order of *DESCENDING* treatment dose and note your initial reaction to any odor present such as "none," "slightly fishy," "foul" or other descriptive term. After having tested all samples, rate the various treatments from best to worst in terms of odor removal. An example of the results from this type of comparative test are shown in Figure 9.10.

Notice that the test shown in Figure 9.10 included alum and polymer treatment. This test was conducted to evaluate PAC application at the flash mixer where the coagulants are added. If chlorine is added near the PAC delivery point, the jar samples should be treated to reflect this. As in all jar testing, the laboratory trials should simulate plant conditions as closely as is possible.

This technique may indicate that PAC treatment alone will not be enough to control the taste and odor problem, which is certainly valuable information. This method is most useful, however, for deciding whether PAC treatment above a certain level provides any additional benefit to water quality. In the example, all jars treated at 6 mg/*L* and higher gave similar results, indicating that a higher PAC dose would not be useful. Results such as these provide guidelines for establishing the most effective treatment at the most economical costs.

One difficulty often overlooked in the use of PAC is the problem of measuring the actual concentration (lbs/gal) of carbon in the slurry tank. For convenience in calculating feed rates, powdered activated carbon slurry tanks are normally loaded at a rate of one pound of PAC per gallon of water. Unfortunately, off-loading from a bulk delivery into multiple tanks usually results in an unequal division of the carbon among the tanks. The following simple laboratory procedures can be used to determine the actual carbon content of the PAC slurry.

Collect a one-liter sample of the carbon slurry from a recently loaded tank after several hours of mixing. Allow this sample to settle for approximately 2 hours in an *IMHOFF CONE*[28] and record the amount of settled carbon as m*L* Carbon/Liter of *SUPERNATANT*[29] of water. Then dry portions of the settled carbon in a laboratory drying oven and weigh them. In this manner, you can calculate the dry weight of carbon per milliliter of settled carbon. From this information it is easy to calculate the amount of carbon per gallon in the slurry. (See EXAMPLE 2 below.) Results from several years of testing at the Stockton East Water Treatment Plant indicate that different carbon manufacturers' carbons have their own characteristics values on a "gram per settled m*L*" basis. Generally, multiplying the m*L*/*L* of settled carbon by a factor, which ranges from about 0.0022 to 0.0028, gives the weight of carbon in the tank, expressed as pounds per gallon.

Powdered activated carbon is an abrasive material. Equipment used to feed PAC often requires more frequent inspection, cleaning, and maintenance than other chemical feed equipment at a water treatment plant to assure proper dosage delivery. Pumping equipment should be routinely inspected for signs of wear. Check valves and slurry suction lines can become clogged with carbon that has caked in the tank. Frequent inspection during actual carbon delivery is necessary when using this equipment.

FORMULAS

To determine the dosage of PAC in either pounds per gallon or pounds per million gallons, we have a choice of two approaches. With the first choice, we convert the milligrams of PAC per liter of water dose from the jar test to pounds per gallon using conversion factors.

$$\text{Desired PAC, lbs/gal} = \frac{(\text{PAC Conc., mg}/L)\ (3.785\ L/\text{gal})}{(1000\ \text{mg/gm})\ (454\ \text{gm/lb})}$$

We multiply by 3.785 liters per gallon to convert the liters to gallons. We divide by 1000 milligrams per gram and 454 grams per pound to convert milligrams to pounds. This gives us an answer in pounds per gallon. Since the pounds of PAC in a gallon of water is very small and we work with millions of gallons of water, we multiply by (1,000,000/1 Million) to get pounds of PAC per million gallons.

The second approach is to refer to our basic loading or chemical feed equation.

$$\text{Feed, lbs/day} = (\text{Flow, MGD})\ (\text{Dose, mg}/L)\ (8.34\ \text{lbs/gal})$$

If we changed the flow from million gallons per day to one million gallons, then this would give us a feed of PAC in pounds per one million gallons.

$$\begin{aligned}\text{Desired PAC, lbs/M Gal} &= (\text{Volume, M Gal})\ (\text{Dose, mg}/L)\ (8.34\ \text{lbs/gal})\\ &= \frac{(1\ \text{M Gal})\ (\text{Dose, mg}/L)\ (8.34\ \text{lbs/gal})}{1\ \text{M Gal}}\\ &= \frac{\text{lbs}}{1\ \text{Million Gal}}\end{aligned}$$

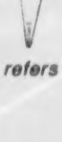
EXAMPLE 1

Results of jar tests indicate that 5 mg/*L* of powdered activated carbon is the most effective dosage for treating a taste and odor problem. What is the desired concentration in pounds per million gallons?

Known	**Unknown**
PAC Conc., mg/*L* = 5 mg/*L*	Desired PAC, lbs/gal

Convert the powdered activated carbon concentration from mg/*L* to pounds/gallon.

$$\begin{aligned}\text{Desired PAC, lbs/gal} &= \frac{(\text{PAC Conc., mg}/L)(3.785\ L/\text{gal})}{(1000\ \text{mg/gm})\ (454\ \text{gm/lb})}\\ &= \frac{(5\ \text{mg}/L)\ (3.785\ L/\text{gal})}{(1000\ \text{mg/gm})\ (454\ \text{gm/lb})}\\ \text{or } &= (0.000042\ \text{lbs/gal})\ \frac{(1{,}000{,}000)}{(1\ \text{Million})}\\ &= 42\ \text{lbs/Million Gal}\end{aligned}$$



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[28] *Imhoff Cone. A clear, cone-shaped container marked with graduations. The cone is used to measure the volume of settleable solids in a specific volume (usually one liter) of water.*

[29] *Supernatant (sue-per-NAY-tent). Liquid removed from settled sludge. Supernatant commonly refers to liquid between the sludge on the bottom and the water surface of a basin or container.*

DATE 5-30-83 TIME 0945 OPERATOR JY/JG

RAW WATER DATA					
SOURCE	PIPELINE				
TEMP	20	°C	pH	8.2	
TURBIDITY	1.8	NTU	COLOR	15	
ALKALINITY	65	Mg/L	HARDNESS	66	Mg/L

MIXING SEQUENCE	RPM	TIME
1.	MAX	2min.
2.	85	8min.
3.	40	16min.
4.		

CHEMICAL (mg/L)		JAR 1	JAR 2	JAR 3	JAR 4	JAR 5	JAR 6
1.	ALUM LIQUID / DRY	6.0	6.0	6.0	6.0	6.0	6.0
2.	CAT POLYMER	1.0	1.0	1.0	1.0	1.0	1.0
3.	PAC	0	2	4	6	8	10
4.							
5.							
6.							
FLOC CHARACTERISTICS	AFTER FLASH MIX						
	AFTER RAPID MIX						
	5 MIN. SLOW MIX						
	10 MIN. SLOW MIX						
	15 MIN SLOW MIX						
FLOC SETTLING	5 MIN						
	10 MIN						
	20 MIN						
	30 MIN						
SETTLED WATER QUALITY	TURBIDITY						
	pH						
	COLOR						
COMMENTS: ODOR:		GRASSY STALE · DIRTY	GRASS · DIRTY DIRTY	SLIGHTLY DIRTY	NONE	NONE	NONE
SUBJECTIVE RATING: (SCALE OF 1 TO 6)		6 (WORST)	5	4	1	1	1

(ALL SIMILAR)

Fig. 9.10 Jar test

ALTERNATE SOLUTION TO EXAMPLE 1

$$\text{Desired PAC, lbs/M Gal} = (\text{Volume Water, M Gal})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (1\ \text{M Gal})(5\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 41.7\ \text{lbs/Million Gal}$$

EXAMPLE 2

A sample of PAC slurry was collected from a slurry tank. The one-liter sample was allowed to settle for 24 hours. The amount of settled carbon was recorded as 50 m*L* Carbon per Liter of supernatant water. Ten m*L* of the settled carbon was dried and found to weigh 20 mg. Calculate the amount of carbon in the slurry in pounds of dry carbon per gallon of water.

Known		Unknown
Sample Size, *L*	= 1 Liter	PAC Slurry, lbs/gal
Carbon Settled, m*L*	= 50 m*L*	
Sample Dried, m*L*	= 10 m*L*	
Dried Sample, mg	= 20 mg	

1. Calculate the amount of settled carbon as mg/m*L*.

$$\text{Settled Carbon, mg}/mL = \frac{\text{Dried Sample Weight, mg}}{\text{Sample Dried, m}L}$$

$$= \frac{20\ \text{mg}}{10\ \text{m}L}$$

$$= 2\ \text{mg/m}L$$

2. Calculate the PAC concentration in the slurry as mg/*L*.

$$\text{PAC Slurry, mg}/L = \frac{(\text{Carbon Settled, m}L)(\text{Settled Carbon, mg/m}L)}{\text{Sample Settled, }L}$$

$$= \frac{(50\ \text{m}L)(2\ \text{mg/m}L}{1\ L}$$

$$= 100\ \text{mg}/L$$

3. Convert PAC Slurry from mg/*L* to pounds PAC per gallon.

$$\text{PAC, lbs/gal} = \frac{(\text{PAC, mg}/L)(3.785\ L/\text{gal})}{(1000\ \text{mg/gm})(454\ \text{gm/lb})}$$

$$= \frac{(100,\ \text{mg}/L)(3.785\ L/\text{gal})}{(1000\ \text{mg/gm})(454\ \text{gm/lb})}$$

$$= 0.000834\ \text{lbs/gal}$$

$$\text{or} \quad = 834\ \text{lbs/Million Gal}$$

9.4413 Filtration considerations with powdered activated carbon. Use of powdered activated carbon for taste and odor removal may intefere with filter performance at a water treatment plant. Caking of PAC on the surface of filters may cause substantially shorter filter runs than otherwise expected. If this occurs, adjustments to improve PAC removal in the settling process may increase the effective length of filtration. An added advantage of optimizing the settling process is the physical removal of taste and odor components with the settled sludge.

A second, and more difficult problem to detect can occur when applying PAC. Because the particle size of powdered activated carbon is nearly microscopic, PAC can penetrate through filters before either head loss or turbidity breakthrough indicate the need for backwashing. Since the PAC particles are black, they absorb light. Therefore, standard *NEPHELOMETRIC*[30] turbidity measurements will not warn of the carbon passing through filters. Penetration of PAC through filters can cause "dirty water" complaints in the distribution system and is particularly apparent to those consumers who have installed home filtration units on their faucets.

Studies conducted at the Stockton East Water Treatment Plant indicate that at that facility carbon penetration through filters is related to both the PAC dose and the hydraulic loading on the filters. At higher flow rates and increased carbon loading on the filters, PAC penetrates through the filter beds much earlier in the filter run than at lower flows or carbon doses.

Powdered activated carbon penetration through a filter bed occurs in approximately the same manner as turbidity breakthrough. A freshly backwashed filter may show the presence of PAC during the recovery period. Following recovery, PAC filtration is excellent, though the length of time this performance is maintained will vary. Depending upon the severity of the PAC penetration problem, special treatment may be necessary. At the Stockton East Plant, filter aid dosage of a nonionic polymer in the range of 0.005 to 0.010 mg/*L* has been used to control PAC penetration during recovery. Continued application of this level of filter aid throughout the run, however, increased the rate of head loss, so filters required backwashing at about the same time that PAC began to appear before in the effluent.

One simple method of determining carbon penetration through a filter is to collect a one liter sample of filter effluent and filter it through a 0.45 μm membrane filter. The presence of PAC in the effluent can be determined from a darkening of the white membrane filter surface. An example of increasing PAC penetration during a filter run as determined by this technique is shown in Figure 9.11.

9.4414 Powdered activated carbon handling. Powdered activated carbon may be purchased either in individual bags (usually 50 pounds (23 kg) bags) or by bulk truck load (up to 40,000 lbs (18,180 kg) per load).[31] Regardless of loading arrangement, by bulk or individual container, powdered activated carbon is usually an unpleasant material to work with at a water treatment plant. Hand loading of a carbon storage tank from bags is a time consuming, dirty job. Offloading of bulk loads is less time consuming but not necessarily any less dirty.

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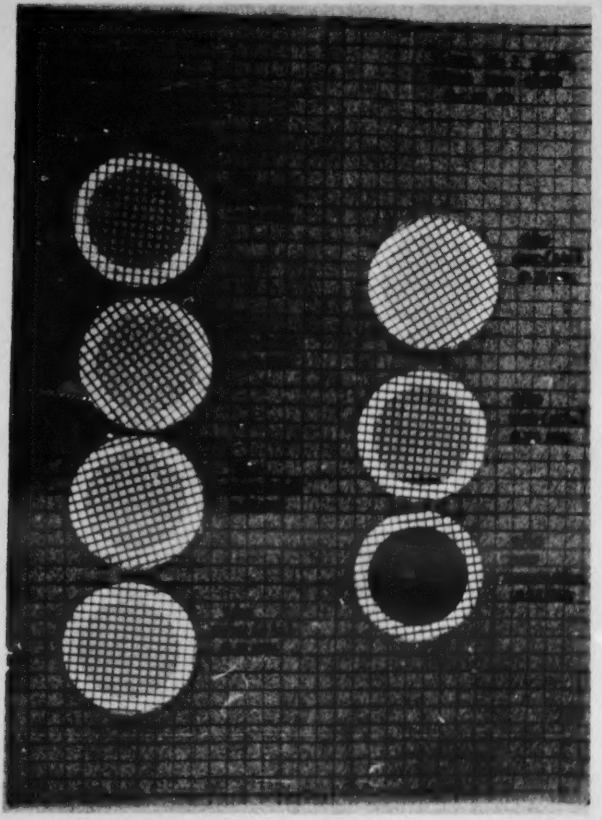
[30] *Nephelometric (NEFF-el-o-MET-rick). A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.*

[31] *Large, one-ton (910 kg) "bladders" or carboys of PAC are available in some areas. Special facilities are required for the use of these containers.*



PAC dose was 10 mg/*L* and filter hydraulic loading was 7.6 GPM/sq ft during test.

Fig. 9.11 PAC penetration through filter

Various types of equipment have been used to control the dust generated during PAC handling. The success of any dust collection system depends upon how well it meets the particular needs of the facility for carbon handling and upon adequate maintenance. Several different approaches to dust control have been used, with more elaborate (and occasionally more successful) designs usually found at larger treatment plants. No matter the type of equipment, dust collectors must be clean and functional at the start of loading operations and further cleaning may be required during the operation to maintain dust-collection effectiveness.

Operators assigned to carbon loading, especially when bags are used, must wear protective clothing. At the very least, goggles, dust masks, and gloves are required. Protective outer clothing is also highly recommended, and showering facilities should be provided for cleaning up after unloading the carbon.

Because powdered carbon will scavenge (actively remove) oxygen from the air, safety procedures for working in confined spaces must be carefully followed when cleaning tanks. Open the tank fully, set up some means of circulating air in the tank, and work in teams — *NEVER WORK ALONE IN A POWDERED CARBON TANK.* Arrange for a spotter (operator) overhead (outside) to watch the cleaning operation closely and be prepared to assist if the need arises. The operator in the tank should wear a safety harness and the oxygen level in the tank must be monitored continuously.

If bags of PAC are to be stored, it is desirable to have them elevated off the floor to prevent caking due to spilled or sprayed water. Wooden pallets work well for this purpose. Carbon is a combustible material, but tends to smolder rather than burn fiercely. A smoldering pallet may be removed by dragging it out of the area, thereby saving the rest of the material from water and fire damage. For this reason, bags should not be stacked more than three or four high on an individual pallet.

Because carbon is combustible, it should be stored away from other materials, especially flammable materials like potassium permanganate ($KMnO_4$) and HTH (High Test Hypochlorite) compounds. If at all possible, an isolated storage facility is highly desirable. Electrical wiring and switches in a carbon storage area should be of special design for flammable storage area use. Whenever there is dust in the air, a spark could cause an explosion. The area should be prominently marked with "No Smoking" signs and this regulation should be strictly enforced.

9.442 Granular Activated Carbon

Granular activated carbon (GAC) is activated in much the same way as powdered activated carbon, although the raw material is usually a lignite coal. Granular carbon, as the name implies, is made up of larger particles than PAC. Typical surface area for GAC is in the range of 400 to 800 square meters per gram (2 to 4 million square feet per pound). The basic adsorption process with granular carbon is the same as with powdered carbon, except that the granular carbon is placed in a stationary bed through which the water flows. Granular carbon filters are capable of filtering water in the same manner as rapid-sand or dual-media filters, and can produce low-turbidity water when operated under similar conditions. GAC filters, which are also referred to as biologically activated carbon filters because of the high levels of bacteria that will develop within the filter bed, have received attention as a means of treating trace organic contamination of drinking water. Generally, the effective life of a GAC filter being used for taste and odor control will be much greater than one used for removal of potentially toxic or carcinogenic trace organics.

Operational procedures for GAC filters closely resemble procedures used with other typical water treatment filters. Two unique considerations for GAC filtration are empty bed contact time (EBCT) and regeneration interval of the carbon. Empty bed contact time is the time that the water is actually in the filter bed (use calculated volume *NOT* including carbon when determining contact time). Successful application of GAC filtration for taste and odor control usually requires a minimum of five minutes, although some cases have required contact times greater than 15 minutes. The EBCT is an important design consideration in GAC units to be used for taste and odor control since the filters must be large enough to provide adequate contact time as the water is filtered.

Periodic regeneration of GAC is necessary as the capacity of the filter to adsorb and retain organic compounds decreases with time. The time between regenerations will vary with the type of material being removed and the volume of water treated. Regeneration is accomplished essentially in the same manner as initial activation, and most utilities replace spent carbon with fresh rather than attempting to regenerate. Regeneration intervals of three to seven years have been reported by utilities using GAC filters for the control of tastes and odors.

Retrofitting of existing filters with GAC is an expensive modification. Initial installation costs are high and long-term expense for regeneration or replacement must be considered. However, in situations where high doses of PAC must be used, or where taste and odor control is required during a substantial portion of the year, evaluation of GAC filtration may indicate that it is a more economical long-term alternative. Because of the expense, thorough investigation in the laboratory and in pilot plant-scale tests should be made prior to plant installation.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 409.

9.4R What adjustments would you make if PAC tends to cake on the surface of the filters?

9.4S What precautions must operators take because powdered activated carbon is so abrasive?

9.4T How can carbon penetration through a filter be detected?

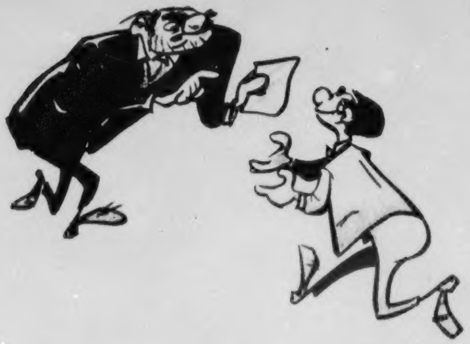
9.4U What is empty bed contact time in a granular activated carbon filter?

9.5 IDENTIFYING A TASTE AND ODOR PROBLEM

Before an effective control strategy for a taste and odor problem can be implemented, the fact that a problem exists must be recognized. This may seem obvious, but delayed response (or no response at all) to the onset of a taste and odor problem in water systems frequently occurs when the problem is not identified at the time it develops. This is especially true in organizations that have had no previous experience with taste and odor problems, or in agencies where complaints from consumers are received at one location while operation and water quality activities are conducted at another.

Every water utility must have an effective communications network in order to deal with all types of consumer complaints. No utility can expect to respond in a timely manner to legitimate consumer dissatisfaction with the water unless it operates under adequate complaint recording and notification procedures.

A good practice is to supply any personnel who deal with the public, either by telephone or in person, with a standard water quality complaint form (Figure 9.12). The form should include, at a minimum, places for recording the date and time of the complaint, the location (address), and as complete a description of the problem given by the consumer as is possible to obtain.

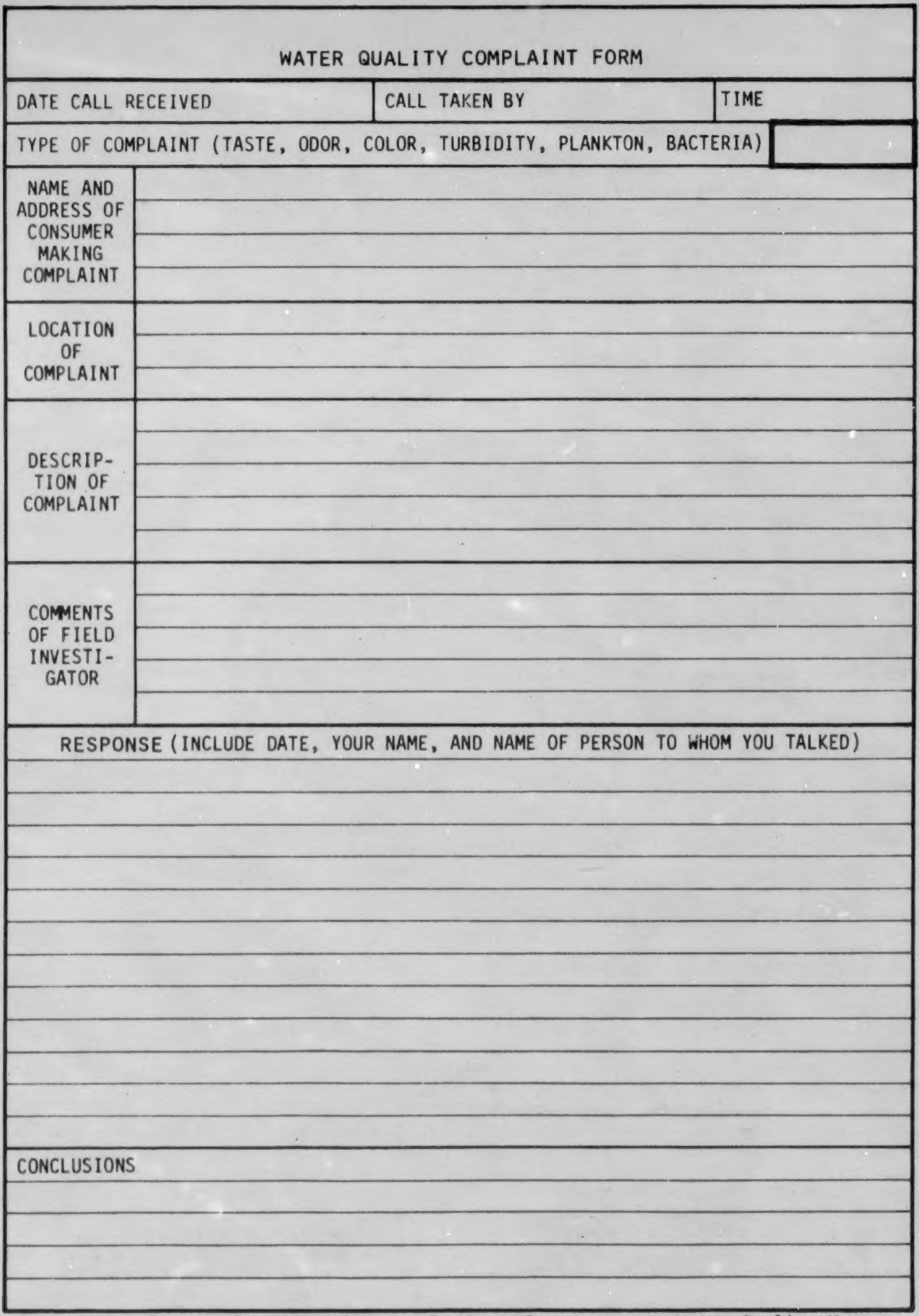


Dissatisfied consumers who contact the water supplier should be treated courteously and respectfully, and considered a valuable resource for the utility in its efforts to provide a high quality water for public consumption. If the problem has already been identified by the utility, the personnel in a position that will involve public contact should be provided with a clear, easily understood explanation of the problem and the actions being taken to correct the situation. If the problem is likely to be corrected in the near future, a date at which the consumer can expect an improvement in the water should be provided.

Notification of the proper personnel within an organization when a complaint has been received is vital to the utility's ability to respond to the problem. When taste and odor complaints are received, it is important that the operators and those responsible for water quality control be provided with the information. Unless the people who are in a position to take action are aware of a problem, no solution is likely to be found. A standard notification procedure for complaints should be established and followed for providing the necessary information to the appropriate units within the organization.

In many cases, it is not necessary to rely on consumer complaints to identify a taste and odor problem or to anticipate the onset of a taste and odor episode. Many utilities are plagued by seasonal tastes and odors in the source water. By keeping complete and accurate records of taste and odor outbreaks it is often possible to predict the start of problems and take corrective action before the consumers are affected. Records must be maintained from one year to the next and organized in such a way as to allow easy retrieval of information.

Routine testing of the raw and finished water for taste and odor quality is an important, on-going activity of every water supplier. Even if no previous record of taste and odor problems exists, testing should be carried out as part of a preventive program. If plant operators identify a problem before it reaches the distribution system, action to control objectionable tastes and odors can be taken without exposing the consuming public to unpalatable water. Taste tests of the finished water and threshold odor number determinations of the raw and finished water should be conducted on a regular basis. The frequency of these tests should be increased during periods of the year when tastes and odors have occurred in the past and during any time that taste and odor treatments are being used.



WATER QUALITY COMPLAINT FORM

DATE CALL RECEIVED	CALL TAKEN BY	TIME

TYPE OF COMPLAINT (TASTE, ODOR, COLOR, TURBIDITY, PLANKTON, BACTERIA) ☐

NAME AND ADDRESS OF CONSUMER MAKING COMPLAINT	
LOCATION OF COMPLAINT	
DESCRIPTION OF COMPLAINT	
COMMENTS OF FIELD INVESTIGATOR	

RESPONSE (INCLUDE DATE, YOUR NAME, AND NAME OF PERSON TO WHOM YOU TALKED)

CONCLUSIONS

See reverse for results of analyses. Send completed copy to Water Quality Manager.

Fig. 9.12 Typical water quality complaint form

(Permission of The Metropolitan Water District of Southern California)

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 409.

9.5A What information should be recorded on a water quality complaint form?

9.5B How should operators be kept informed of taste and odor problems?

9.5C What tests can operators conduct to identify taste and odor problems before they reach the consumer?

9.6 DEVELOPING A TASTE AND ODOR CONTROL STRATEGY

The first step in developing a taste and odor control strategy is to determine the extent of the problem. If only one complaint has been received, the problem may exist within the consumer's home plumbing and no action at the treatment plant can be expected to improve the situation. If several complaints have been received from one area of the distribution system but the rest of the system has not experienced problems, the problem is probably the result of local conditions. Factors which may affect one area of a system include chlorine residuals above or below normal, low flows due to low demands, or a cross-connection. However, because other, more serious water quality problems may be associated with a localized taste and odor problem, prompt response to such complaints is required. In systems that use multiple water sources, taste and odor complaints may arise when a new source of water is provided to an area. The complaints do not necessarily mean one water is better than the other — only that the two are different. This frequently occurs in systems that use both a surface supply and groundwater, although use of two or more different surface supplies may also lead to complaints. When the utility switches back to the original source, more complaints can be expected. In cases like these, utility personnel who handle complaints must be made aware of the situation so they can explain to consumers that a change in supply does not necessarily mean a change in water quality.

If the entire system is being affected by a taste and odor problem, it is important to try to determine just where the problem originates. If complaints can be associated with the use of a particular raw water supply, changing to an alternative source may resolve the problem. If an alternative water supply is not available, then an evaluation of conditions which might be responsible for the deterioration of water quality is necessary.

Reviewing water quality test results from different locations within the supply system may indicate that a problem has developed at a particular point. Conduct a physical inspection of the suspected area and correct any conditions which appear to be adversely affecting water quality. The raw water source, storage facilities, raw water transmission systems, and facilities at the treatment plant all should be evaluated as potential sources of the problem. Finished water storage facilities within systems have also been sources of tastes and odors for many water facilities.

Collect samples at a number of locations from both the supply source and distribution system for analysis in the laboratory. Examine raw water samples for increased algal populations and for bacterial levels. The laboratory tests should include standard plate counts and plate counts that have been held at 20°C, or *AMBIENT WATER TEMPERATURE*,[32] for a period of five to ten days. Many bacteria grow relatively slowly and will not be apparent until the fifth to seventh day of incubation.

Investigations to determine the cause of a taste and odor episode may take several weeks before providing any useful information. While the laboratory is conducting tests to try to determine the cause, the plant operators are faced with the question of how to treat the problem. Evaluation of different treatment techniques should be done in cooperation with the laboratory, but testing needs to be done in such a manner that the results are useful to plant operation, especially during the initial stages of a taste and odor problem.

Do not waste time evaluating treatment programs that are not available for use at the treatment plant. In order to concentrate your initial efforts in treatment evaluation in those areas that the plant can most readily use, write up an inventory of available treatment techniques. (Ideally this information should be collected and updated before a taste and odor problem begins.) Review the operational status of installed equipment during this inventory process. For example, powdered activated carbon feed systems that are not operable because of repair or maintenance work will not be much help in controlling current tastes and odors.

In addition to looking at readily available treatment processes, identify alternative methods for taste and odor control at other locations. An example would be the capacity to superchlorinate the plant influent, or possible locations upstream of the plant at which potassium permanganate could be applied. Collecting this information in the early stages of a taste and odor outbreak can be useful in developing control programs that are both effective and realistic for a particular facility.

Once you have identified the options available for treating the taste and odor, determine what treatment or combination of treatments is effective in reducing or eliminating the objectionable qualities of the water. Test each available treatment in the laboratory for its ability to improve water quality; combinations of treatments should also be investigated. Most treatment plants faced with taste and odor problems use a combination of two or three treatments to produce finished water of the best possible quality. In one particular situation, for example, it may be possible to use $KMnO_4$ at the raw water intake, powdered activated carbon at the flash mixer, improved coagulation, flocculation and sedimentation, and above-normal chlorination before filtration to reduce the taste and odor properties of the water to a level that the consumers find acceptable. The most important aspect of a taste and odor control evaluation program is to test as many possible combinations as you reasonably can to determine the most effective approach to solving the problem.

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[32] *Ambient Water Temperature (AM-bee-ent). Temperature of the surrounding water.*

Each potential treatment scheme may require changes in the various steps involved. Dose control at each step of the process is critical so that the individual processes work in harmony and do not create additional problems while trying to control the original source of the consumer complaints. In most cases, for example, it is both ineffective and uneconomical to superchlorinate and add powdered activated carbon at the same point in the process stream. But at the same time, it may be unwise to completely shut down prechlorination just because carbon is being fed at a point close to the chlorine diffuser. Without prechlorination, algae may rapidly develop in downstream facilities at the treatment plant. The savings associated with reduced chlorine use may well be offset by the increase in problems associated with the algal growth in the treatment works.

In developing a taste and odor control program, it is useful to remember that many of the available methods require some minimum dose level in order to be effective. Application of amounts greater than this minimum dose may provide no further benefit to water quality and, in some cases, may actually impair water quality. For example, tests show that a water supply required 10 mg/*L* PAC for taste and odor control. To save money, you use only 3 mg/*L* PAC. However, at 3 mg/*L* there is almost no improvement in the water quality so you may actually be wasting money at this dosage level. The water requires *AT LEAST* 10 mg/*L* PAC to show any significant improvement. At the same time, treating the water with 15 mg/*L* PAC does not improve the quality over that which would be achieved by the 10 mg/*L* treatment. Similarly, treatment with 0.5 mg/*L* of $KMnO_4$ may reduce the objectionable qualities of the water while 0.3 mg/*L* may do no good and 1.0 mg/*L* may well create colored-water problems in addition to the existing taste and odor problem.

Sophisticated laboratory analytical methods have been developed to measure and identify taste- and odor-causing compounds at the part-per-trillion (ppt) level. The Metropolitan Water District of Southern California applied specialized analytical methods to the detection of geosmin and methylisoborneol, compounds known to cause earthy-musty odors and tastes in water. Other laboratories may be expected to develop similar capabilities in the future. These very specialized analyses can provide valuable information for evaluating the source and cause of a taste and odor problem, and the effectiveness of various treatment techniques in controlling the problem.

Increased public awareness of potential health hazards associated with drinking water supplies and the legitimate concern of consumers for the quality of the water that they receive have emphasized the need for prompt and effective action during taste and odor incidents. Constant testing of both raw and treated water and adequate training of operators responsible for water treatment are required to provide the public with high quality, safe, and pleasing supplies of drinking water.

PREVENTION OF TASTE AND ODOR IN PUBLIC WATER SUPPLIES IS USUALLY MORE EFFECTIVE AND MORE ECONOMICAL THAN TREATMENT. However, every water system is subject to unusual and uncontrollable changes in source quality. Familiarity with available treatment alternatives and training in the operation and application of these alternatives is an important aspect of operator development and improvement.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 409.

9.6A What factors could cause taste and odor complaints in a local area of a distribution system?

9.6B Which locations in a water supply system might contribute to a taste and odor problem?

9.6C Why is it important to write out and update a list of options available for treating taste and odor problems?

9.7 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.9, Steps in Solving Problems. Check all of the arithmetic in this section using an electronic pocket calculator. You should be able to get the same answers.

9.8 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 14, "Taste and Odor Control."
2. *TEXAS MANUAL*, Chapter 5, "Tastes and Odors in Surface Water Supplies (Interference, Nuisance, and Taste- and Odor-Producing Organisms)."

End of Lesson 3 of 3 Lessons on TASTE and ODOR CONTROL

DISCUSSION AND REVIEW QUESTIONS

Chapter 9. TASTE AND ODOR CONTROL

(Lesson 3 of 3 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 409. The question numbering continues from Lesson 2.

18. How would you determine whether activated carbon is an effective means of removing specific tastes and odors?
19. Why should an overhead spray system be used when powdered activated carbon is being loaded into slurry tanks?
20. How does powdered activated carbon influence the performance of filters?
21. What safety precautions should be exercised when cleaning a tank that stores powdered activated carbon?
22. How should a water supplier treat dissatisfied consumers who contact them with a complaint?
23. What is the first step in developing a taste and odor control strategy?
24. Why should a taste and odor control evaluation program test as many combinations of treatment schemes as possible?
25. What are the most important steps an operator can take to prevent the development of taste and odor problems?

SUGGESTED ANSWERS

Chapter 9. TASTE AND ODOR CONTROL

(Lesson 3 of 3 Lessons)

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 381.

9.0A Taste and odor problems may occur at a water treatment plant on a persistent, seasonal, occasional, or infrequent basis.

9.0B Taste and odor, along with colored water complaints, are the most common types of water quality complaints received by a water utility.

9.0C Loss of public confidence in the water utility's ability to provide safe, high quality water may be the most damaging effect of taste and odor problems.

Answers to questions on page 382.

9.1A Tastes and odors may be caused by either natural or man-made conditions.

9.1B Taste and odor conditions could develop in raw water sources, conveyance facilities, treatment plants, chlorination stations, finished water storage reservoirs, distribution systems and consumer plumbing.

Answers to questions on page 382.

9.1C Microbial growths leading to objectionable tastes and odors can occur during any time of the year, and in any area of a water system.

9.1D Microbial populations can contribute to unpleasant tasting and smelling water by (1) the production of metabolic by-products and (2) the release of cellular materials.

9.1E The conditions that develop after a large microbial growth may increase taste and odor problems if the decomposition process is accelerated. Decomposition may cause both metabolic by-product formation and release of cellular materials.

Answers to questions on page 384.

9.1F Nutrient levels in a water supply can be increased by either natural conditions or human activity in the watershed.

9.1G Types of materials in runoff waters which can lead to oxygen depletion are nitrogen- and phosphorus-containing compounds and organic matter.

9.1H The diurnal dissolved oxygen cycle is caused by algae producing oxygen (photosynthesis) during the day and creating supersaturation conditions. During the night algae remove dissolved oxygen from the water (respiration) and cause the dissolved oxygen level to approach zero.

Answers to questions on page 384.

9.1I Contamination from septic tank and leach field systems in rural areas and resort or vacation developments may be caused by high densities of homes and people, locations too close to rivers, soils with inadequate percolation rates, poor maintenance and substandard installation.

9.1J Industrial waste dischargers can cause taste and odor problems from the effects of all facilities that discharge into the water supply and also from process and mechanical failures of the industrial waste treatment processes.

9.1K The sources of chemical spills include accidents at industrial plants, chemical storage facilities, or during transportation.

Answers to questions on page 386.

9.1L Many municipal water intake facilities have been located upstream of major agricultural areas to avoid possible contamination of the water supply by fertilizers, pesticides, and herbicides. Siting of intake facilities above heavily cultivated agricultural lands also helps protect against tastes and odors.

9.1M Sources of agricultural wastes that may cause taste and odor problems in a water supply include high density animal feeding and dairy operations and runoff from cultivated fields.

9.1N Microorganisms will grow in plant debris and sludges even in the presence of a strong chlorine residual. Microbial growths in these materials can lead to foul, septic, musty, or other types of tastes and odors.

Answers to questions on page 387.

9.2A Taste and odor problems are most likely to develop in any parts of the system which are used to store, transport, or regulate untreated water because these parts may provide a suitable habitat for oganisms that produce objectionable tastes and odors in drinking water due to absence of chlorine residual.

9.2B Chemicals such as chlorine and activated carbon tend to mask any changes in taste and odor quality that may be occurring.

9.2C Potential sources of tastes and odors in a water treatment plant include areas where debris and sludge can accumulate, and the walls, channels and weirs where algal and slime (bacterial) growth can occur.

9.2D Complaints regarding "chemical," "gasoline," or "pesticide" tastes or odors should alert you to the possibility of a cross-connection.

Answers to questions on page 388.

9.3A If settled sludges and other debris are allowed to accumulate for an extended time, they will become septic and impart a foul taste and odor to the water.

9.3B Portions of a water treatment plant are usually taken out of service for inspection and cleaning during the winter months when flows are lower and full plant capacity is not needed to meet the community's water demands.

9.3C Taste and odor treatment equipment should be capable of operating properly at all times so the equipment will work whenever a problem occurs.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 389.

9.4A The two broad categories of taste and odor treatment methods are (1) removal and (2) destruction.

9.4B Tastes and odors caused by algae can be removed most economically in a water treatment plant by improving coagulation and sedimentation. This procedure may lengthen filter runs by achieving removal of the algae in the sedimentation basin rather than by filtration.

9.4C The reaction of chlorine on algal cells results in the release of objectionable cellular materials into the water. This may increase taste and odor problems.

Answers to questions on page 391.

9.4D Aeration is best suited for treating odor problems caused by volatile compounds. Aeration is less successful in treating taste problems because these are more often associated with less volatile compounds.

9.4E Aeration systems can be designed to either pass the air through the water, or to pass water through the air.

Answers to questions on page 393.

9.4F Odors that can often be significantly reduced by chlorination include fishy, grassy or flowery odors.

9.4G The use of chlorine in waters containing phenols could result in the production of highly objectionable chlorophenolic compounds. These compounds cause noticeable tastes and odors even in concentrations 40 to 200 times *LESS* than the original phenol.

9.4H If a permanganate overdose does occur, treat with powdered activated carbon if the facilities are available. A second alternative is to increase the pH of the water for a short time to increase the rate at which the manganese is precipitated.

9.4I Permanganate storage facilities must be dry and well ventilated as moisture in the atmosphere can cause caking of the material. This will cause the feeder to clog and prevent accurate delivery of the permanganate.

9.4J Adequate permanganate dust control and ventilation is important because permanganate and moisture create a very corrosive mixture which will attack metal, including electrical connections.

Answers to questions on page 395.

9.4K Laboratory and pilot-scale testing of the effectiveness of ozonation as a taste and odor control process should be conducted before full-scale installation because of the specialized equipment requirements and costs.

9.4L Chlorine dioxide must be generated on-site because it is unstable and cannot be stored.

9.4M Chlorine dioxide has been used to treat tastes and odors caused by industrial pollution, especially in cases where chlorine has intensified the problem.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 397.

9.4N The two forms of activated carbon used in water treatment are powdered and granular (PAC and GAC).

9.4O Activated carbons are rated on the basis of a "phenol number" or an "iodine number."

9.4P Powdered activated carbon should be applied at plant flash-mixing facilities because carbon must contact the material to be removed in order for adsorption to occur.

9.4Q If a caked layer of floating carbon starts to form on the surface of the water in the slurry tank, stop the operation, check mixers and sprayers, and break up any cake that has formed. If all equipment is operating properly, the loading rate must be reduced to the level at which the system can adequately mix the carbon into a slurry.

Answers to questions on page 403.

9.4R If PAC tends to cake on the surface of filters, adjust the settling process to remove more PAC before it reaches the filters.

9.4S Because powdered activated carbon is such an abrasive material, equipment used to feed PAC often requires more frequent inspection, cleaning, and maintenance than other chemical feed equipment. Pumping equipment should be routinely inspected for signs of wear. Frequent inspection during actual carbon delivery is necessary when using this equipment.

9.4T Carbon penetration through a filter can be detected by passing one liter of filter effluent through a 0.45 μm membrane filter. The presence of PAC in the effluent can be determined from a darkening of the white membrane filter surface.

9.4U Empty bed contact time is the time that the water is actually in the filter bed.

Answers to questions on page 405.

9.5A Information that should be recorded on a water quality complaint form includes date and time of complaint, location (address), and a complete description of the problem.

9.5B Operators should be informed of taste and odor problems by personnel who receive and log consumer complaints. Also, if operators keep good records they can anticipate when seasonal taste and odor problems will develop and be prepared to respond at the appropriate time.

9.5C Operators can conduct taste tests of the finished water, and threshold odor number determinations of the raw and finished water on a regular basis.

Answers to questions on page 406.

9.6A Factors that could cause taste and odor complaints in a local area of a distribution system include chlorine residuals above or below normal, low flows due to low demands, or a cross-connection.

9.6B Locations which might contribute to a taste and odor problem include the raw water source, storage facilities, raw water transmission systems, facilities at the treatment plant, and finished water storage facilities within the system.

9.6C A list of available options for treating taste and odor problems is essential so that when a problem develops, the lab can immediately run tests on the effectiveness of available solutions. Such a list would eliminate time wasted investigating unrealistic solutions.

OBJECTIVE TEST

Chapter 9. TASTE AND ODOR CONTROL

Please write your name and mark the correct answer on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Water rated as poor quality by consumers always has health related problems.
   1. True
   2. False

2. In many cases, the definite cause of a taste and odor problem is never found.
   1. True
   2. False

3. If treatments of raw water are begun only after large populations of organisms have developed, the effect may be to accelerate the decomposition process and worsen the taste and odor outbreak.
   1. True
   2. False

4. Microorganisms normally cause the oxygen concentration in water to decrease.
   1. True
   2. False

5. Microbial populations are relatively high in unpolluted waters.
   1. True
   2. False

6. New homes never have taste and odor problems because the household plumbing is made of all new materials.
   1. True
   2. False

7. When evaluating a taste and odor complaint, the entire system from the source of the raw water supply to the consumer's tap should be considered as a potential source of the problem.
   1. True
   2. False

8. The surface of a strongly stratified reservoir is a good place to start looking for the causes of taste and odor problems.
   1. True
   2. False

9. Adequate maintenance and housekeeping are a necessary part of an effective taste and odor control program.
   1. True
   2. False

10. Prevention of tastes and odors is usually more economical than treatment at the plant.
    1. True
    2. False

11. Many odors in raw water are readily treated by chlorine.
    1. True
    2. False

12. Use of chlorine is always an effective means of controlling tastes and odors caused by algae.
    1. True
    2. False

13. Aeration can be used to treat taste- and odor-producing organic materials.
    1. True
    2. False

14. Air blowers are very effective aeration devices.
    1. True
    2. False

15. Air blowers can serve as very effective mixing devices.
    1. True
    2. False

16. Air blowers may be effective in removing highly volatile substances such as hydrogen sulfide.
    1. True
    2. False

17. Phenolic tastes in water can be removed by chlorine.
    1. True
    2. False

18. Potassium permanganate may be used to remove color from water.
    1. True
    2. False

19. Chlorine is a stronger oxidant than ozone.
    1. True
    2. False

20. Powdered activated carbon (PAC) may be applied to water at any point in the process after filtration.
    1. True
    2. False

21. Jar tests should be used to determine the necessary powdered activated carbon dose required to treat a specific taste and odor problem.
    1. True
    2. False

22. Accurate determination of the threshold odor numbers of many jar tests can be accomplished by performing all the tests in a short period of time.
    1. True
    2. False

23. Powdered activated carbon will scavenge (remove) oxygen from the air.
    1. True
    2. False

24. Some compounds may cause more objectionable tastes and odors after chlorination than before treatment.
    1. True
    2. False

25. Taste and odor complaints may occur when the source of water is switched from a surface water to a groundwater source.
    1. True
    2. False

MULTIPLE CHOICE

26. Consumers will rate water as poor quality if the water
    1. Has coliforms.
    2. Is colored.
    3. Looks dirty.
    4. Smells bad.
    5. Tastes bad.

27. Tastes and odors in water can be caused by
    1. Algae.
    2. Bacteria.
    3. Diatoms.
    4. Fish.
    5. Fungi.

28. What types of tastes and odors may be imparted to drinking waters by bottom sediments from rivers and channels?
    1. Earthy
    2. Musty
    3. Perfume
    4. Salty
    5. Septic

29. Types of pollution which may enter a municipal water supply upstream from a water treatment plant and cause tastes and odors include
    1. Agricultural wastes.
    2. Chemical spills.
    3. Industrial discharges.
    4. Irrigation runoff.
    5. Urban runoff.

30. Inadequately treated municipal wastewaters may enter a water supply due to
    1. Excessive flows in raw water source.
    2. High wastewater flows.
    3. Mechanical breakdowns.
    4. Oversized facilities.
    5. Process failures.

31. Individual wastewater disposal systems in rural areas may contribute pollutants to the water supply due to
    1. Locations too close to rivers.
    2. Poor maintenance.
    3. Proper siting of systems.
    4. Soils with inadequate percolation rates.
    5. Substandard installation.

32. What should be the *MOST IMPORTANT CONCERN* of an operator after a chemical spill?
    1. Aquatic life
    2. Cleanup procedures
    3. Fish life
    4. Health-related effects
    5. Tastes and odors

33. Undesirable taste- and odor-causing wastes found in urban runoff include
    1. Animal droppings.
    2. Coliforms.
    3. Greases.
    4. Oils.
    5. Phenols.

34. Water quality indicators measured when searching for the location of a taste and odor problem include
    1. Coliforms.
    2. Color.
    3. pH.
    4. Threshold odor number.
    5. Turbidity.

35. When inspecting a segment of the water system suspected of being the origin of a taste and odor problem, look for
    1. Expanded commercial development.
    2. New industrial activity.
    3. Tributary streams.
    4. Unauthorized connections.
    5. Unintentional cross-connections.

36. Types of tastes and odors which may develop in settled sludges and debris in water treatment plants include
    1. Bitter.
    2. Fishy.
    3. Grassy.
    4. Rotten egg.
    5. Swampy.

37. Treatment methods capable of removing tastes and odors from drinking water include
    1. Adsorption.
    2. Chlorination.
    3. Coagulation.
    4. Sand filtration.
    5. Sedimentation.

38. Which of the following easily detectable odors in water can often be decreased by chlorination?
    1. Fish
    2. Flower
    3. Grass
    4. Phenol
    5. Pungent

39. Removal of odor-producing substances that are volatile is known as
    1. Chlorination.
    2. Coagulation.
    3. Degasification.
    4. Oxidation.
    5. Reduction.

40. Chemical oxidants used to control tastes and odors include
    1. Chlorine.
    2. Chlorine dioxide.
    3. Ozone.
    4. Potassium permanganate.
    5. Sulfur.

41. The appropriate dose of powdered activated carbon for any particular problem will vary depending upon the
    1. Concentration of the material to be removed.
    2. Contact time.
    3. Location of application points.
    4. Mixing available.
    5. Nature of the problem.

42. The raw material used for producing granular activated carbon normally is
    1. Argon.
    2. Carbon dioxide.
    3. Gravel.
    4. Lignite coal.
    5. Sand.

43. The minimum empty bed contact time for granular activated carbon filtration for taste and odor control is
    1. 5 minutes.
    2. 15 minutes.
    3. 30 minutes.
    4. 60 minutes.
    5. 120 minutes.

44. Local taste and odor complaints in a distribution system may be caused by
    1. A cross-connection.
    2. Algal blooms in source reservoir.
    3. Below-normal chlorine residuals.
    4. Low demands for water.
    5. Septic sludge deposits in water treatment plant.

45. Calculate the volume of a rectangular sedimentation basin 9-feet deep, 23-feet wide, and 49-feet long.
    1. 1,127 cu ft
    2. 8,430 cu ft
    3. 10,143 cu ft
    4. 75,870 cu ft
    5. 84,953 cu ft

46. Determine the theoretical detention time in hours for a rectangular sedimentation basin with a volume of 76,000 gallons when the flow is 0.9 MGD.
    1. 0.084 hrs
    2. 0.20 hrs
    3. 2.0 hrs
    4. 2.5 hrs
    5. 15.0 hrs

End of Objective Test

CHAPTER 10

PLANT OPERATION

by

Jim Beard

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OBJECTIVES

Chapter 10. PLANT OPERATION

Following completion of Chapter 10, you should be able to:

1. Monitor and control water treatment processes, and
2. Safely operate and maintain a water treatment plant.

Chapter 10 will help you accomplish these objectives by instructing you how to:

1. Regulate flows,
2. Apply chemicals and adjust dosage,
3. Prepare operating reports and records,
4. Maintain equipment and facilities,
5. Develop daily operating procedures for your plant,
6. Respond to emergency conditions,
7. Handle consumer complaints, and
8. Implement energy conservation measures.

GLOSSARY

Chapter 10. PLANT OPERATION

BOD (pronounce as separate letters) BOD

Biochemical Oxygen Demand. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

COMPOSITE SAMPLE (come-PAH-zit) COMPOSITE SAMPLE

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

CONTINUOUS SAMPLE CONTINUOUS SAMPLE

A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples. Frequently several taps (faucets) will flow continuously in the laboratory to provide samples from various processes in a water treatment plant.

GRAB SAMPLE GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

PICO PICO

A prefix used in the metric system and other scientific systems of measurement which means 10^{-12} or 0.000 000 000 001.

PICOCURIE PICOCURIE

A measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second.

POLYELECTROLYTE (POLLY-ee-LECK-tro-lite) POLYELECTROLYTE

A high-molecular-weight (relatively heavy) substance having points of positive or negative electrical charges that is formed by either a natural or man-made process. Natural polyelectrolytes may be of biological origin or derived from starch products and cellulose derivatives. Man-made polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Often called a POLYMER.

POLYMER POLYMER

A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

POWER FACTOR POWER FACTOR

The ratio of the true power passing through an electric circuit to the product of the voltage and amperage in the circuit. This is a measure of the lag or load of the current with respect to the voltage.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

CHAPTER 11. PLANT OPERATION

(Lesson 1 of 2 Lessons)

10.0 GOALS OF PLANT OPERATION

In the operation of water treatment plants, competent and responsible operators try to achieve three basic objectives:

1. Production of a safe drinking water,
2. Production of an aesthetically pleasing drinking water, and
3. Production of drinking water at a reasonable cost.

From a public health perspective, production of a safe drinking water, one that is free of harmful bacteria and toxic materials, is the first priority. Federal, state and local regulations and drinking water standards control all aspects of treatment of public water supplies to insure the delivery of safe water to consumers.

In addition to providing safe water, it is also important to produce a high quality water which appeals to the consumer. Generally, this means that the water must be clear (free of turbidity), colorless, and free of objectionable tastes and odors. Consumers also want water supplies that do not stain plumbing fixtures and clothes, do not corrode plumbing fixtures and piping, and do not leave scale deposits or spot glassware.

Not only do consumers want safe and pleasing water, but they want it at a reasonable cost. In this era of rapidly increasing energy costs, treatment plant operators must examine all plant processes to trim costs and maintain a cost-effective operation.

Consumer sensitivity to the environment (air quality, water quality, noise) has significantly increased in recent years. With regard to water quality, consumer demands have never been greater. In some instances, consumers have substituted bottled water for drinking water and cooking purposes.

Again, maintaining a standard of sanitary excellence and meeting the increasing demands of consumers for high quality drinking water requires conscientious operators to produce and maintain the quality of the water from the plant to the consumer's tap.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.0A What is the first priority for operating a water treatment plant?

10.0B What type of water is appealing to consumers?

10.1 DRINKING WATER CONSIDERATIONS

10.10 Drinking Water Regulations

For centuries people have judged water quality on the basis of taste, smell, and sight. To a large degree, this is still true today. However, many consumers today are demanding water which is not only free of objectionable tastes and odors, but also free of harmful bacteria, organic and inorganic chemical contaminants, turbidity, and color.

Current water quality standards include both federal and state regulations. Following passage of the Safe Drinking Water Act (PL 93-523) in 1974, the U.S. Environmental Protection Agency (EPA) was charged with the responsibility of developing and implementing national drinking water regulations. A summary of the maximum contaminant levels (MCLs) established by these regulations is shown in Tables 10.1 and 10.2. Primary regulations establish MCLs based on the health significance of the contaminants while the secondary standards are established based on aesthetic considerations.

Operators must realize that water can degrade in the distribution or delivery system. For this reason, compliance with the MCLs is generally measured at the consumer's tap. An exception to this rule is turbidity, which for compliance determination is measured at the point the water enters the distribution system.

Under the Safe Drinking Water Act, each state was given the option of assuming primary enforcement responsibility for public water systems on the condition that the state would adopt regulations at least as stringent as the EPA regulations and would implement adequate monitoring and enforcement procedures. Most states have agreed to these terms and have been delegated primary responsibility by the EPA.

TABLE 10.1 ENVIRONMENTAL PROTECTION AGENCY PRIMARY DRINKING WATER REGULATIONS

CONSTITUENT	MAXIMUM CONTAMINANT LEVEL[a]
Inorganic Chemicals	
Arsenic	0.05
Barium	1
Cadmium	0.010
Chromium	0.05
Fluoride	1.4 - 2.4[b]
Lead	0.05
Mercury	0.002
Nitrate (as N)	10
Selenium	0.01
Silver	0.05
Organic Chemicals	
Chlorinated Hydrocarbons	
Endrin	0.0002
Lindane	0.004
Methoxychlor	0.1
Toxaphene	0.005
Chlorophenoxys	
2, 4-D	0.1
2, 4, 5 - TP Silvex	0.01
Total Trihalomethanes	0.10
Physical	
Turbidity*	1 TU[c]
Radioactivity	
Radium 226 + 228	5 p Ci/*L*[d]
Gross Alpha	15 p Ci/*L*
Gross Beta	50 p Ci/*L*
Tritium	20,000 p Ci/*L*
Strontium 90	8 p Ci/*L*
Microbiological	
Coliform Bacteria*	1 organism/100 m*L*

[a] mg/*L* unless noted.
[b] Value depends on temperature.
[c] Under certain circumstances 5 TU may be allowed.
[d] p Ci/*L* means picoCurie per liter.
* *NOTE:* The two items marked * are more or less under the control of the operator; all other items are not influenced significantly by plant treatment processes.

NOTE: YOUR REGULATORY AGENCY MAY HAVE STRICTER REGULATIONS. CONTACT APPROPRIATE OFFICIALS TO DETERMINE THE REGULATIONS WHICH APPLY TO YOUR PLANT.

10.11 Monitoring Program

As mentioned in previous chapters, operators perform a variety of laboratory tests on source water samples, process water samples, and finished water samples to monitor overall water quality and to evaluate process performance. The type of water sample used for a particular analysis will vary depending on the nature or purpose of the analysis. But in all cases, it is important to stress that the water sample must be representative of actual conditions of the entire flow being sampled.

TABLE 10.2 ENVIRONMENTAL PROTECTION AGENCY SECONDARY DRINKING WATER REGULATIONS

CONSTITUENT	MAXIMUM CONTAMINANT LEVEL[a]
Chloride	250
Color*	15 Color Units
Copper	1
Foaming Agents (MBAS)	0.5
Hydrogen Sulfide*	0.05
Iron*	0.3
Manganese*	0.05
Odor*	3 Threshold Odor Number
pH*	6.5 - 8.5
Sulfate	250
TDS	500
Zinc	5

[a] mg/*L* unless noted.
* *NOTE:* All items marked * are more or less under the control of the operator; all other items are not influenced significantly by plant treatment processes.

NOTE: YOUR REGULATORY AGENCY MAY HAVE STRICTER REGULATIONS. CONTACT APPROPRIATE OFFICIALS TO DETERMINE THE REGULATIONS WHICH APPLY TO YOUR PLANT.

GRAB SAMPLES[1] are usually adequate for making periodic measurements of water quality indicators. They are especially useful when measuring indicators that may change quickly after collection, such as coliforms, pH and temperature. When variations in water quality are expected, *COMPOSITE SAMPLES*[2] may be more appropriate. Ideally, process control measurements should be made on a continuous basis by special instrumentation.

A summary of process monitoring guidelines and sample points is shown in Figure 10.1. The frequency of sampling for individual process control water quality indicators will vary from hourly to perhaps once per day, depending on the quality of the source water and the importance of the indicator being evaluated. Thus, certain water quality indicators such as turbidity will be routinely monitored (every two hours), while others such as alkalinity are sampled on a less frequent basis (once per shift).

10.12 Turbidity Removal

Most municipal plants built to treat surface water are designed to remove turbidity, and turbidity is the single water quality indicator over which water treatment plant designers and operators have the greatest control.

In a well designed and operated treatment plant, very high turbidity removals can be achieved under optimum conditions, while poorly operated treatment plants (inadequate

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[1] *Grab Sample. A single sample collected at a particular time and place which represents the composition of the water only at that time and place.*

[2] *Composite Sample (come-PAH-zit). A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.*

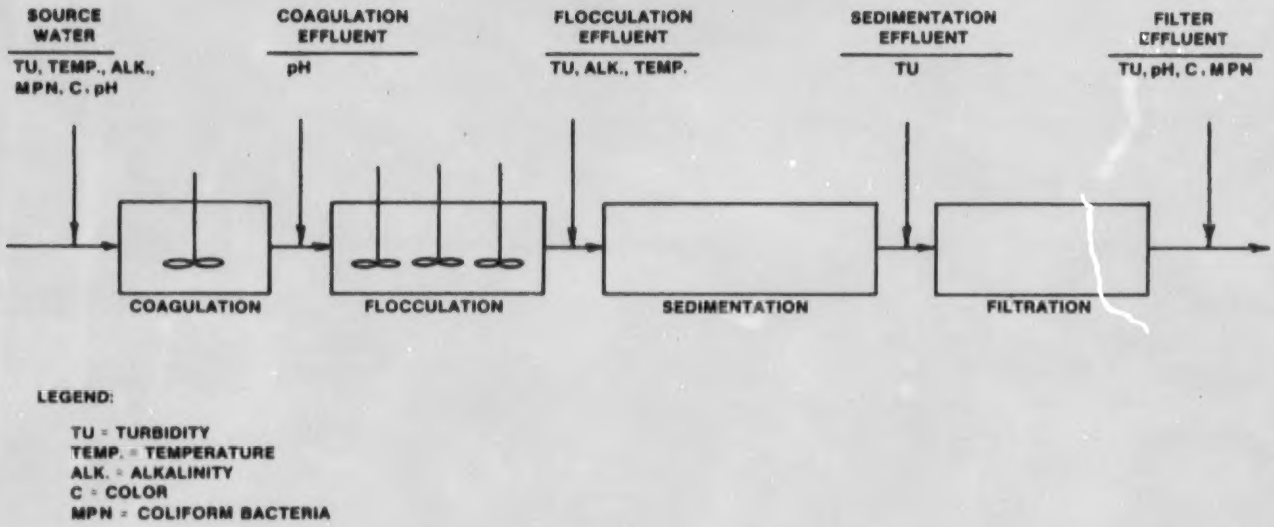


Figure 10.1 Summary of process monitoring guidelines and sample points

pretreatment and filtration) may only achieve relatively low turbidity removals (filtered water turbidities greater than 1.0 TU). This range of turbidity removal effectiveness is extremely important when one considers the relationship between turbidity and bacteria and other pathogenic organisms. There is considerable evidence which shows that filtered waters with high levels of turbidity cannot be effectively disinfected.

Thus, the goal of all water treatment plants should be to produce a filtered water with the *LOWEST PRACTICAL LEVEL* of turbidity. Many water treatment plants in the United States treating surface water, routinely produce filtered water turbidities in the range of 0.05 to 0.3 TU. A recommended target turbidity level is 0.1 TU.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.1A Grab samples are used when measuring what types of water quality indicators?

10.1B Why are high levels of turbidity removal important?

10.2 DAILY OPERATING PROCEDURES

10.20 Prepare a List for Your Plant

Throughout this manual we have explained the step-by-step procedures to effectively operate a water treatment plant. In this section we are going to outline a checklist of daily activities for the operators of a "typical" plant. *YOU SHOULD PREPARE A SIMILAR LIST FOR YOUR PLANT.* Consider our list and all of the information in this manual. Take into account the size of your plant, type and condition of your plant, raw water characteristics, your distribution system, the number of operators available to help and their skills. A sample checklist is shown in Table 10.3. (In the boxes an "N" means normal, an "A" means abnormal, and an "O" means out of service.) By using this example and the information contained in this manual, you should be able to prepare a checklist for your plant which reflects your specific needs.

10.21 Daily Tasks

1. Review what has happened during the last shift or since you left the plant and respond to any problems.
   a. An important part of reviewing plant operations is exchanging information with the operator on duty. Shift assignments should be arranged to provide an overlap at shift changes to permit a brief time period (perhaps 15 to 30 minutes) for operators to exchange important information on the status of the plant and special problems which need attention or monitoring.
   b. Your review should include a check of raw and finished water quality for any changes. Especially important is the turbidity and chlorine residual of the finished water in the clear well.
   c. Review system pressures.
   d. Check clear well storage and levels of other reservoirs in the distribution system.
   e. Examine records of raw water and distribution system pumping. Inspect records or charts of flow meters and/or total hours run by each pump.
   f. Check the status of each filter. Do any of them need to be backwashed?
2. Prepare for the day. You have two major concerns: to provide your consumers with drinking water of suitable *QUALITY* and sufficient *QUANTITY*.
   a. *QUALITY*

      Water quality is controlled mainly by the proper application of chemicals. Be sure you have sufficient chemicals to meet today's demands and future demands.

      (1) Alum. Check daily use and amount in storage.

TABLE 10.3 ROUTINE PLANT CHECKLIST

DATE ______________ OPERATOR ______________________________

SHIFT 1 ☐ Midnight-8 a.m. 2 ☒ 8 a.m.-4 p.m. 3 ☐ 4 p.m.-Midnight

1. *INTAKE STRUCTURE*
   a. Status of Bar Screens 1 [N] 2 [A]
   b. Status of Intake Pumps 1 [N] 2 [N] 3 [O]
   COMMENTS: Bar screen in Bay No. 2 partially clogged with debris. Will clean this shift.

2. *CHLORINATION SYSTEM*
   a. Status of Evaporators 1 [N] 2 [N]
   b. Status of Chlorinators 1 [N] 2 [N]
   c. Status of Chlorine Residual Analyzer [N]
   d. Status of Booster Pumps 1 [O] 2 [O]
   e. Chlorine Feed Points Pre- [N] Intermediate [N] Post [N]
   COMMENTS:

3. *COAGULANT FEED SYSTEMS*
   a. Status of Alum Feed Pumps 1 [N] 2 [O]
   b. Status of Polymer Feed Pumps 1 [N] 2 [O]
   COMMENTS:

4. *FLASH MIXER/FLOCCULATION SYSTEMS*
   a. Status of Flash Mixer [N]
   b. Status of Flocculators-Basin No. 1 1 [N] 2 [N] 3 [A] 4 [N]
   -Basin No. 2 1 [O] 2 [O] 3 [O] 4 [O]
   COMMENTS: Flocculator No. 3 in Basin No. 1 starting to develop a whine. Will monitor and advise maintenance.

5. *SEDIMENTATION BASINS*
   a. Basins in Service 1 [N] 2 [O]
   b. Status of Sludge Pumps 1 [N] 2 [O]
   c. Sludge Lagoons in Service 1 [O] 2 [N] 3 [O]
   COMMENTS:

6. *FILTER STATUS*
   a. Filters in Service 1 [N] 2 [N] 3 [N] 4 [O]
   b. Backwash Cycle: Auto [N] Manual [O]
   c. Filter Run Termination: Loss of Head [N] Time [O]
   d. Status of Filter Aid System [O]
   COMMENTS:

7. *FINISHED WATER CLEAR WELL AND PUMP STATION*
   a. Clear Well Level [A]
   b. Status of Pumps 1 [N] 2 [N] 3 [O]
   c. Status of NaOH Feed System [N]
   COMMENTS: Reservoir level at 9:30 a.m. is low. Will evaluate system demand and adjust plant flow rate.

USE OF CHECKLIST

1. An entry in a box indicates that the unit is in service or out of service and its status (condition).
2. The status of an item is indicated by inserting an "N" (meaning normal), an "A" (meaning abnormal), or an "O" (meaning out of service) in the proper box.
3. Any "A" entry should be briefly explained in the comments section for that system.
4. This checklist is designed to supplement other plant records such as the daily operations log which requires more detailed information and entries. The checklist should not be used in lieu of these other records.

(2) Polymers. Record daily use, level of day tank and amount in storage.

(3) Chlorine. Record daily use, weigh containers and determine amount in storage.

b. *QUANTITY*

Ideally we would like to select an influent pumping rate which will allow our plant to operate at a constant rate for the next 24 hours. This rate should allow the plant to meet all demands and maintain adequate reserves in the clear well and service storage reservoirs. The items listed below should be considered when selecting an influent pumping rate.

(1) Examine the previous day's circumstances.

(a) How much water was treated and pumped to the distribution system?

(b) What were the weather conditions? Was it hot? Overcast? Lawns being watered? Freezing conditions?

(2) Consider the previous day's average flow based on raw water pumping and records of water pumped to the distribution system.

(3) Consider storage in clear well. Ideally, the clear well will be nearly full at the start of each day.

(4) After considering items (1), (2) and (3), select a raw water pumping rate that will allow the plant to operate at a constant rate during the next 24 hours. The clear well will be drawn down during the high demand period during the day and filled at night. See Section 10.4, "Regulation of Flows," for additional details.

3. Walk through your plant. Start at the intake or headworks and follow the flow of water through your plant to the clear well.
   a. *LOOK* for anything unusual or different in the appearance of the water as it goes through each process. Inspect each piece of equipment.
   b. *LISTEN* for any unusual or different noises from the equipment.
   c. *FEEL* the equipment for excessive temperature and vibrations.
   d. *SMELL* for any signs of developing odors in your finished water. Also be aware of any signs of equipment burning or overheating.
   e. *TASTE* and smell your finished water for any changes or undesirable characteristics.
   f. *SAFETY*. Whenever you walk through your plant, be alert for safety hazards. If you observe anyone using unsafe procedures or if you observe an unsafe condition, correct the situation immediately.
4. Respond to minor problems not taken care of previously.
5. Collect samples for quality control and analyze samples.
   a. Check turbidity, chemical doses (jar tests), chlorine residual, pH, alkalinity, and coliforms.
   b. Check calibrations on finished water recording turbidimeter and chlorine residual analyzer.
6. Perform all scheduled preventive maintenance.
7. Record all necessary data and be sure all records are up to date.
8. Order supplies, including chemicals.
9. Review safety program.

10.22 Tasks to be Done During Day

1. Backwash filters (if automatic, everything OK?).
2. System pressures must be observed regularly. If system pressures are monitored and transmitted to a control room, then the operator on duty will be responsible for constant surveillance. If system procedures fluctuate beyond established ranges, adjust pumping rates or number of pumps on line as necessary.
3. Monitor the main control board. Charts provide important information as to present plant status. Alarm panel lights also provide important status information. Beware of lights "ON," particularly "RED" lights as these usually require immediate attention.
4. Storage level in clear well. If clear well level is monitored in a control room, then operator on duty will be responsible for surveillance and any necessary adjustments of influent pumping rates.
5. Pumping rates
   a. Pumping rates into distribution system should be adjusted to maintain system pressures and demands. Pressures should be monitored throughout the system and whenever the pressures start to drop, increase the pump speed or place an additional pump in service.
   b. Raw water pumping rates should be adjusted as necessary to maintain desired levels in clear well throughout the day.
6. Quality control checks
   a. Collect samples for quality control and analyze.
   b. Check turbidity, chemical doses (jar tests), chlorine residual, pH, and alkalinity.
   c. Inspect chlorination system. Is it working properly? Are there any leaks?
7. Repeat these tasks as often as necessary.

10.23 At the End of the Day

Perform the following tasks at the end of your shift or before leaving your plant at night:

1. Repeat the tasks listed under Section 10.22, "Tasks to be Done During Day."
2. Anticipate raw water and finished water pumping requirements during the night.
3. Be sure all chemical dosage facilities are prepared to operate until the next operator comes on duty.
4. Secure the plant for the night by checking outside lighting and security systems and locking the plant.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.2A What should be an operator's first task upon arrival at a water treatment plant?

10.2B How does an operator control finished water quality?

10.2C What tasks should an operator do during the day?

10.2D What tasks should an operator do at the end of the day?

10.3 PROCESS INSTRUMENTATION AND CONTROLS

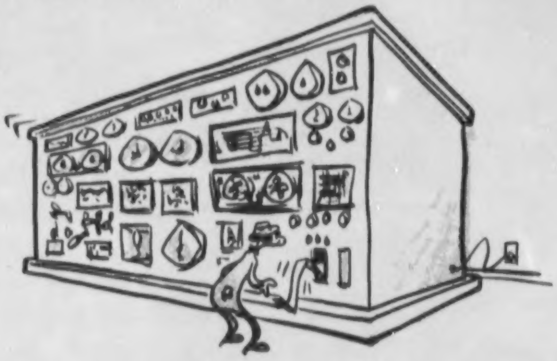
10.30 Monitored Functions

To assist you in providing consumers with a safe and palatable supply of drinking water, instruments and controls are used to measure, monitor, record, control, and signal the breakdown of many of the process functions on a continuous or intermittent basis. Regardless of how simple or complex the instrumentation and control systems are for your plant, *YOU* are responsible for controlling plant operation. A summary of typically monitored functions is listed in Table 10.4. In smaller water treatment plants the number of functions monitored may be limited to the essential functions only. The most common methods of sensing these process functions are listed in Table 10.5.

TABLE 10.4 SUMMARY OF COMMONLY MONITORED FUNCTIONS[a]

FUNCTION	MONITORED LOCATION
Flow	• Raw Water • Service Water • Chemical Solutions • Filters • Wash Water • Sludge • Finished Water
Level	• Chemical Tanks and Hoppers • Filters • Wash Water Tank • Clear Well • Recovery Basins
Chlorine Residual	• Each Unit Process • Finished Water
Turbidity	• Raw Water • Each Unit Process • Individual Filters • Finished Water
pH	• Raw Water • Each Unit Process • Finished Water
Weight	• Chlorine Cylinders • Chemical Feeders (Loss-in-Weight Type)
Pressure	• Service Water • Plant Air Supply • Water Level (Bubblers) • Effluent Pump Station • General Piping
Loss-in-Head (Differential Pressure)	• Individual Filters
Sludge Density	• Sedimentation Basin • Solids Disposal Piping
Conductivity	• Raw Water • Finished Water
Temperature	• Raw Water

[a] Adapted from Stone, Reference 1.



Instrumentation and controls are communication devices that transmit information (data) from measuring locations in the water treatment plant to a central data collection point (usually a control room). In most modern water treatment plants, this central data collection point is the Main Control Panel (see Figure 10.2). This is the "nerve center" of the plant and is located in the operations control room. From this single location, the operator can monitor and control most of the major process functions. In many modern water treatment plants, sophisticated electronic methods provide virtually automatic control over major process functions. However, manual controls must be available to back up critical functions in water treatment plants so operators can override the automatic system when necessary.

TABLE 10.5 SUMMARY OF COMMON SENSING METHODS[a]

FUNCTION	SENSING METHOD
Flow	• Venturi Meters (Differential Pressure) • Propeller Meter • Magnetic Meter • Sonic Meter • Rotameter
Level	• Float • Bubbler • Probe • Pressure Cell • Sonic
Chlorine	• Amperometric (Electrode) • Colorimetric
Turbidity	• Surface Scatter (High Turbidity) • Nephelometric (Low Turbidity)
pH	• Amperometric (Electrode)
Weight	• Scales (Mechanical) • Load Cells (Electronic or Pressure)
Pressure	• Bourdon Tube (Mechanical) • Electronic • Differential Pressure (D.P. Cell)
Loss-in-Head	• Differential Pressure
Conductivity	• Electronic
Temperature	• Electronic

[a] Adapted from Stone, Reference 1.

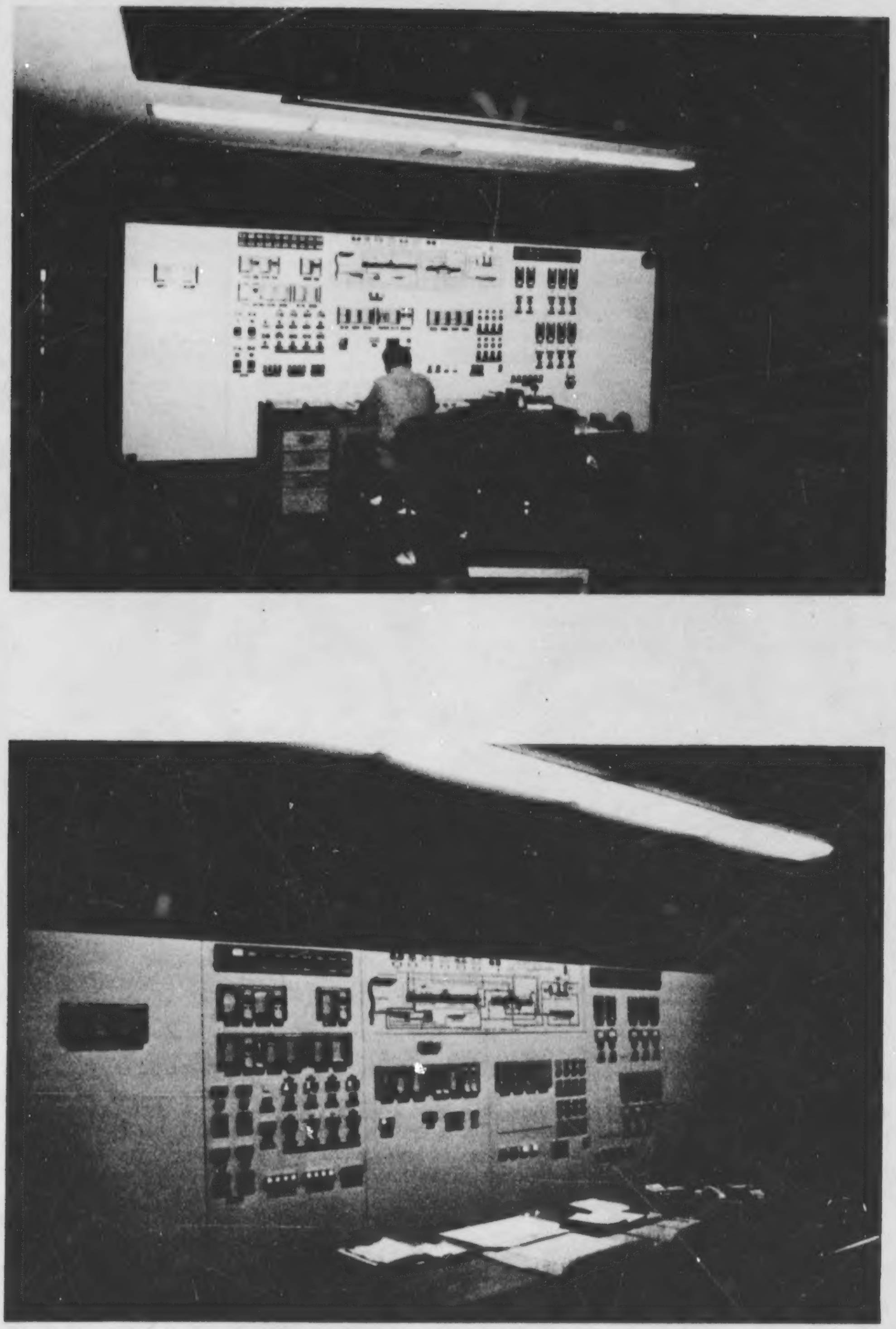


Fig. 10.2 Main Control Panel in control room

10.31 Signal Transmission Methods

10.310 Methods Available

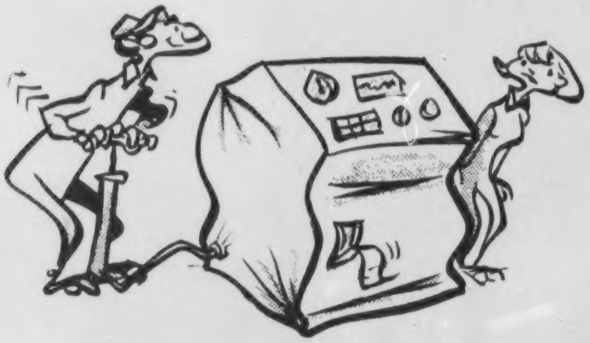
There are numerous methods of transmitting data from sensing or measuring locations in the water treatment plant to a central control point. Methods used to transmit data include mechanical, pneumatic, hydraulic, electrical and electronic. However, electronic systems (millivolt or milliamp) have become the popular choice. When certain data must be transmitted over long distances (greater than about 1500 feet or 450 m), other systems such as telephone tone, microwave, or radio transmission may be used.

10.311 Mechanical

The most basic type of instrumentation is purely mechanical. These devices are easily understood, reliable, and are generally the most economical. Examples of mechanical devices include:

1. Float valves,
2. Pressure relief valves,
3. Pressure gages,
4. Indicators (valve position and fluid level),
5. Switches (high/low level, pressure), and
6. Scales (chlorine and other chemical weighing devices).

These mechanical devices have been used for many years and are still in use at many of the older plants. Many newer types of sensing and transmitting devices are based on the principles of these mechanical devices.



10.312 Pneumatic

Pneumatic (using air pressure or vacuum) measuring and transmission devices are particularly safe and reliable, and service can be maintained during short-term power outages. In these systems, data are usually transmitted through small-diameter (⅛ to ¼ inch or 3 to 6 mm) copper tubing. Usually, the air supply for pneumatic instrumentation must be dried to prevent condensation in equipment signal lines, and it must be filtered to remove particle contaminants that could clog orifices. Most pneumatic transmitters produce a signal in the range of 3 to 15 psi (0.2 to 1.0 kg/sq cm or 1.4 kPa to 6.9 kPa), and the signal is usually linear within that range (i.e., 3 psi = 0%, 9 psi = 50%, and 15 psi = 100% of scale).

One drawback of pneumatic systems is that the air volume in the signal lines causes some dampening of the signal. This means that on longer transmission lines (say 300 to 500 feet or 90 to 150 m), delays of 5 to 30 seconds may be experienced. Normally, the maximum transmission distance for pneumatic signals is about 1000 feet (300 m). Therefore, pneumatic devices frequently provide a direct readout at the measuring location. For remote readings the pneumatic signal is converted to an electronic signal and then transmitted to a receiver in a control room.

10.313 Hydraulic

Hydraulic (using liquid pressure) instrumentation, unlike pneumatic signals, operates over a broad range of pressures. Water, water and oil, and glycerol are frequently used system fluids. The fluid is normally conveyed through small diameter pipe (¼ to 1 inch or 6 to 25 mm) constructed of copper or steel.

Hydraulic signals are not dampened like pneumatic signals so signal transmission is virtually instantaneous. These systems can be used to transmit weight (load cells) and pressure data, and are also commonly used to operate (power) mechanical equipment such as valves.

Hydraulic systems are probably the least used signal transmission method in water treatment plants.

10.314 Electronic

Electronic signal transmission has become the most commonly used data gathering and transmission method.

Water treatment plant process data are usually transmitted within a range of 4 to 20 millivolt signals (often expressed as milliamp signals). A major advantage of electronic signal transmission is that extremely low potential (voltage) electronic signals from field devices (such as electrodes in water) can be amplified to millivolt signals. Another advantage of electronics is that converting signals (transducing) from one form to another is quite easy. Solid-state circuitry can be used in this regard to convert variable sensing data to linear signals.

Electronic signals are used to activate common electrical power and control circuitry (120 and 240-volt) to start and stop or otherwise control equipment, and to activate audible and visual alarms. The following list is a summary of the functions commonly performed using electronic instrumentation:

1. Indication (gages (analogs), digital indicators, and cathode ray tube displays),
2. Recording (strip or circular charts),
3. Data logging (magnetic tape or disks),
4. Alarm (audible or visual), and
5. Control (computer, solid-state circuitry, or relay logic systems).

10.315 Electrical

Electrical signals (other than electronic) are also commonly used to perform a variety of signaling, telemetry, and control functions. Ordinary alternating current (A.C.), either 120-volt or 240-volt, is frequently used. However, other voltages, such as 6, 12, and 24-volt (A.C. or D.C.) are commonly used for control when a shock hazard may present a problem.

Common functions performed with electrical signals include the following:

1. On-off control (make or break by means of switches),

2. Time-impulse control (signals are transmitted for only a portion of a cycle, i.e., 15 seconds), and
3. Pulse rate control (pulses or short transmissions of power).

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.3A How are data transmitted over distances greater than about 1500 feet?

10.3B What precautions must be exercised when using air for pneumatic data transmission?

10.3C What types of transmission fluids are commonly used in hydraulic systems?

10.3D List the functions commonly performed by electronic signals.

10.32 Control Methods

Many of the instrumentation systems used in water treatment plants are combinations of the previously described systems, and are commonly referred to as *HYBRID* systems.

Perhaps the most widely used method of automatically controlling pumps, valves, chemical feeders, and other devices, is known as *RELAY LOGIC*. Relay logic is a method of switching electrical power on and off in accordance with a predetermined sequence (logic) by means of relays, process switches and contacts, timers, and manual switches. Virtually any sequence of operational control can be achieved using relay logic. This approach is very reliable because the system can be operated by manual controls if the need arises.

10.33 Computers

In many of the newer water treatment plants, computers (micro-processors) are being used to monitor and record data on process functions and status. However, critical functions are wired for manual operation if the computer fails. A cathode ray tube (CRT) is commonly used to visually display selected data when requested by an operator.

Increasing use of computers will minimize the number of visual indicators (such as strip chart recorders) required to monitor, record, and display water treatment process data.

Computers are being used to optimize process performance as well as monitor and record data. This means increased safety and reliability of plant operation. The expanding use of computers adds an entirely new dimension to water treatment plant operation, and provides challenging new opportunities for operators with the foresight to prepare themselves. For additional information and details, see Chapter 19, "Instrumentation."

YOU must realize that plant instrumentation does not relieve you of your *RESPONSIBILITY* to make operational decisions and to exercise operational control. In many "automated" plants the operators yield their human authority to an electronic black box; therefore, making themselves slaves to automation. However, this automation was meant to be the slave to human control.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.3E What is a hybrid instrumentation system?

10.3F What is relay logic?

10.4 REGULATION OF FLOWS

10.40 Need for Flow Regulation

Water treatment plant flow rates fluctuate with total system demand. Thus, distribution system or consumer demands generally control water treatment plant operations. Demands for water vary depending on the following considerations:

1. Time of day,
2. Day of week,
3. Season of the year,
4. Prevailing weather conditions,
5. Manufacturing demands (canneries), and
6. Unusual events (fire, main breaks).

In order to meet these variable system demands, adequate source capacity and treated water storage volume are essential. Usually, a minimum distribution system operating pressure is established for all water service connections, and this value establishes the basic guideline for system operation. When the pressure falls below a predetermined value, additional flow must be provided. This demand establishes the finished water demand. Thus, most water treatment plants are operated on a "demand-feedback" basis, whereby finished water flow requirements (consumer demands) establish raw water and in-process flow requirements. In small water treatment systems the plant may only need to be operated for a portion of the day (one eight-hour shift) in order to produce sufficient water for reservoir storage to meet distribution system demands during a 24-hour period.

In order to estimate how much water needs to be treated each day, you need to analyze current storage levels in clear wells (or plant storage reservoirs) and in distribution system service storage reservoirs. Also the expected consumer demand for the day must be estimated. This is where your historical flow records can be very helpful. Important items to consider include trends during the past few days. Is the weather changing and causing an increase or decrease in demand for water? In the late spring or early summer, increasing temperatures can cause an increase in demands for water to irrigate gardens and lawns. High winds and freezing conditions can also create shifts in demands. In many communities the life style of the people can create predictable demands for water on certain days of the week. For example when people wash their clothes or cars, or do their yard irrigation. Another factor which may influence demand for water is whether or not children are in school or at home "playing with water." In summary, to estimate the flow rate or amount of water to be treated each day by your water treatment plant, review:

1. Clear well and distribution storage needs,
2. Yesterday's and historical consumer demands, and
3. Weather forecasts.

Actual regulation of the flow to water treatment plants depends on the method used to deliver water to the plant. If the raw water is transmitted by gravity from a reservoir through a pipe under pressure, then the flow can be changed by adjusting a butterfly or plug-type valve. If pumping is involved, then a change in the pumping rate and/or the number of pumps in service will be required.

Raw water pumps are either constant speed or variable speed units. In constant rate pumping units using multiple pumps, adjustments of flow is accomplished by adding or removing pumps in service to produce the desired flow. Variable speed pumps can be adjusted by changing the drive speed of the pumps to produce the desired flow. Pumps used to pump finished water into the distribution system operate in a similar manner. Many pumps are designed to operate most efficiently in a fairly narrow range of flow and pressure conditions. Therefore, the individual operating characteristics of each pump should be considered so that the most efficient pumping mode can be selected.

The following example shows how to adjust the raw water flow rate to meet system demands. Let's assume that a clear well has a maximum storage capacity of five million gallons, with three million gallons currently in storage, and the plant flow rate is 1.5 MGD.

If the plant is being operated on a continuous basis, the raw water flow rate should be adjusted to approximately three MGD depending upon weather conditions and the day of the week.

EXAMPLE

The three MGD will meet the demand of 1.5 MGD and allow us to add 1.5 MG during the 24-hour period to storage. We did not try to make up the entire two million gallon deficit in storage, since this could possibly cause overfilling of the reservoir if distribution system demands suddenly drop.

In this same example, if the plant only operated for eight hours per day, then the flow rate would have to be increased by a factor of three [(3)(3 MGD) = 9 MGD] to achieve the same results.

Let's further assume that the plant has an operating capacity of five MGD and the raw water pumping station has one 1,500 GPM constant speed pump and two 1,000 GPM constant speed pumps. (A flow of one MGD is approximately equal to a flow of 700 GPM for 24 hours). At the initial flow rate of 1.5 MGD only one of the 1,000 GPM pumps would be needed to provide this flow (1,000 GPM for 24 hours is almost equal to 1.5 MGD). Both 1,000 GPM units in service would almost provide the desired 3 MGD flow (actual flow would be 2.9 MGD). Constant rate distribution system pumps would be adjusted in a manner similar to that just described.

After you have made the flow rate change, you should verify the actual flow rate by reading the raw water flow measuring device. You should periodically check the storage levels (elevations) in the clear well and service storage reservoirs to determine if they are maintaining the desired storage volumes. Plant flows should be adjusted whenever major changes in consumer demand occurs.

10.41 Clear Wells

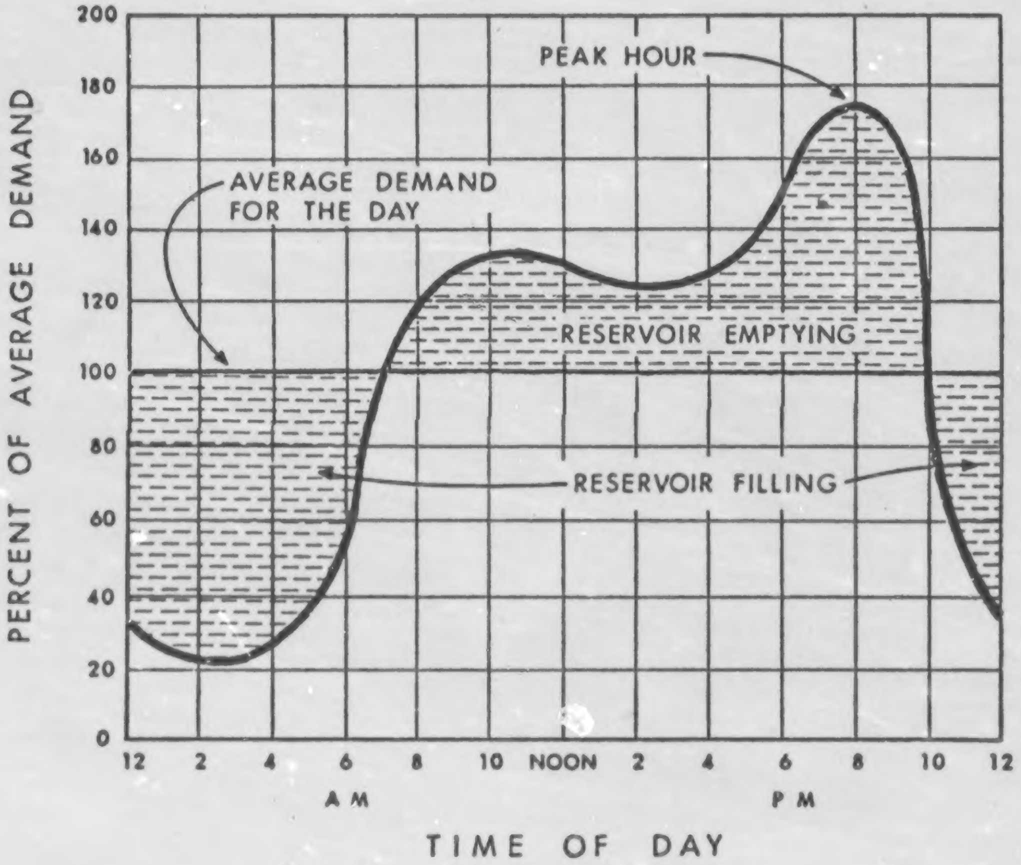
Clear wells (or plant storage reservoirs) are an important part of the water treatment plant; they provide necessary operational storage to average out high and low flow demands. The reservoir is filled when demands are low to compensate for peak periods which draw the level down (see Figure 10.3). This reservoir also acts as a buffer that prevents frequent on/off cycling of finished water pumps and permits planned changes in treatment plant operation.

10.42 Treatment Process Changes

In order to maintain adequate clear well and distribution system water storage levels, raw or source water flow changes may be required (either increases or decreases). Raw water flow changes should take into account the travel or detention time between the source of supply (river or lake) and the treatment plant.

When storage demands change and require adjustments in the flow of water through a plant, you may also be required to perform the following functions:

1. Adjust chemical feed rates,
2. Change filtration rates,
3. Perform jar tests,
4. Observe floc formation and floc settling characteristics,



(Note that the hatched area above the 100% line equals the hatched area below that line)

Fig. 10.3 Typical daily variation of system demand

(From *WATER DISTRIBUTION OPERATOR TRAINING MANUAL*, by California-Nevada Section, AWWA)

5. Monitor process performance,
6. Collect process water quality samples, and
7. Visually inspect overall process conditions.

Some of these changes may occur automatically if your plant has flow-paced chemical feeders. Changes in chemical feed rates (coagulants and chlorine) are required when using manually operated chemical feeders because they are generally set to feed a specific amount of chemical, and this amount is dependent on the rate of flow. Adjustment and calibration of chemical feeders is discussed in Chapter 4, "Coagulation and Flocculation."

Filter production is commonly varied with changing plant flow rates as described in Chapter 6, "Filtration." However, filter control systems may also be designed to automatically maintain uniform filter flow rates. For greater control, the number of filters in service can be changed by starting or stopping individual filter units.

In addition to the above considerations, each of the other unit treatment processes (coagulation, flocculation, and sedimentation) is designed to operate over a broad range of flow rates. However, in some instances, major flow changes may require either adding or removing facilities from service.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.4A What factors influence the amount of water which must be treated each day?

10.4B How are clear wells operated during peak system demands for water?

10.4C How are filters operated when changes in demand occur?

10.5 CHEMICAL USE AND HANDLING

10.50 Need for Chemicals

A wide variety of chemicals are used in the water treatment plant in the production of a safe and palatable drinking water supply. They play a crucial role in controlling process performance and producing a high quality water. Chemicals are used in the following aspects of water treatment:

1. Clarification (turbidity reduction),
2. Disinfection,
3. Taste and odor control,
4. Algae control,
5. Corrosion/scaling control,
6. Water softening, and
7. Fluoridation.

Operators should be thoroughly familiar with the types of chemicals used in water treatment, specific chemical selection and applications, evaluation methods for determining performance, and safe storage and handling techniques.

10.51 Types of Chemicals

The most commonly used chemicals for water treatment are described in Table 10.6. The American Water Works Association has developed standards (see AWWA Standards, Section B — Treatment) for many of these chemicals which help to assure that only quality chemicals are used in water treatment. These standards should be referred to when ordering treatment chemicals.

The choice of specific chemicals to use in a given water treatment plant will vary depending on source water quality, type of treatment to be performed, availability of chemicals, and to some degree on economic considerations.

The initial selection of specific chemicals and anticipated feed rates for a given application is frequently determined by pilot plant testing of the specific source water. Pilot plant tests are usually performed by the water treatment plant designer by constructing a "small scale" treatment plant at or near the source of supply. Pilot tests provide the designer, as well as the treatment plant operator, with valuable information on the "treatability" of a given source of supply over a broad range of water quality conditions.

10.52 Storage of Chemicals

Water treatment chemicals can be stored in a number of ways including:

1. Solid (dry) form (bags, cartons, drums),
2. Liquid form (drums, tanks, cylinders), or
3. Gaseous form (cylinders).

Chemicals should be stored in accordance with the manufacturer's written recommendations and requirements established by regulatory agencies. Regardless of the storage method, always anticipate future chemical requirements so that an ample supply will be on hand when needed. A good practice is to maintain at least a 30-day supply of all commonly used treatment chemicals. Keep a running account of chemical use and storage inventory on a daily basis. Minimum storage quantities should be established for each type of chemical, and this information will indicate when chemicals should be ordered. Minimum storage quantities for some chemicals such as chlorine may be established by regulatory agencies. *NEVER ALLOW THE SUPPLY OF CHLORINE TO DROP BELOW A 15-DAY SUPPLY AT THE PLANT SITE.*

EXAMPLE 1

Shown below is the amount of chlorine used by a small water treatment plant during one week.

Day of Week	Mon	Tues	Wed	Thurs	Fri	Sat	Sun
Chlorine Used, lbs	43	39	34	38	39	37	29

What was the daily average use of chlorine in pounds per day?

KNOWN	UNKNOWN
Chlorine Used Each Day of Week	Daily Average Use of of Chlorine, lbs/day

Calculate the daily average use of chlorine in pounds per day.

$$\text{Ave. Use, lbs/day} = \frac{\text{Sum of Chlorine Used Each Day, lbs}}{\text{Total Number of Days, day}}$$

$$= \frac{43 \text{ lbs} + 39 \text{ lbs} + 34 \text{ lbs} + 38 \text{ lbs} + 39 \text{ lbs} + 37 \text{ lbs} + 29 \text{ lbs}}{7 \text{ days}}$$

$$= \frac{259 \text{ lbs}}{7 \text{ days}}$$

$$= 37 \text{ lbs/day}$$

NOTE: We used a seven-day average so each day of the week would be considered.

EXAMPLE 2

The chlorine cylinder on line has less than one day's chlorine supply remaining. Four 150-pound chlorine cylinders are in storage. The plant uses an average of 37 pounds of chlorine per day. How many day's supply of chlorine is available?

KNOWN	UNKNOWN
Chlorine Cylinders = 4 Cylinders	Supply of Chlorine, days
Cylinder Wt., lbs/cyl = 150 lbs/cyl.	
Ave. Use, lbs/day = 37 lbs/day	

Calculate the available supply of chlorine in days.

$$\text{Supply of Chlorine, days} = \frac{(\text{Cylinder Wt., lbs/cyl.})(\text{No. of Cylinders})}{\text{Ave. Use, lbs/day}}$$

$$= \frac{(150 \text{ lbs/cyl.})(4 \text{ Cylinders})}{37 \text{ lbs/day}}$$

$$= \frac{600 \text{ lbs Chlorine}}{37 \text{ lbs Chlorine/day}}$$

$$= 16 \text{ days}$$

TABLE 10.6 CHEMICAL TYPES AND CHARACTERISTICS[a]

CHEMICAL NAME	CHEMICAL FORMULA	COMMERCIAL CONCENTRATION	COMMENTS
COAGULANTS			
Aluminum Sulfate (Alum, granular)	$Al_2(SO_4)_3 \cdot 14\ H_2O$	47-50% ($Al_2(SO_4)_3$)	Acidic
Ferric Chloride	$FeCl_3 \cdot 6\ H_2O$	59-61% $FeCl_3$	Acidic
Ferric Sulfate	$Fe_2(SO_4)_3 \cdot 9\ H_2O$	90-94% Fe $(SO_4)_3$	Acidic, Staining
Ferrous Sulfate	$FeSO_4 \cdot 7\ H_2O$	55% ($FeSO_4$)	Cakes Dry
Cationic Polymer	—	Varies	Negatively Charged
Anionic Polymer	—	Varies	Positively Charged
Nonionic Polymer	—	Varies	
DISINFECTION			
Sodium Hypochlorite	NaOCl	12-15% (Cl_2)	Solution
Calcium Hypochlorite (HTH)	$Ca(OCL)_2 \cdot 4\ H_2O$	65-70% (Cl_2)	Powder
Chlorine	Cl_2	99.8% (Cl_2)	Gas/Liquid
Anhydrous Ammonia	NH_3	99-100% (NH_3)	Gas/Liquid
Ammonium Hydroxide	NH_4OH	29.4% (NH_3)	Solution
Ammonium Sulfate	$(NH_4)_2SO_4$	6.3% (NH_3)	Cakes Dry
Chlorine Dioxide	ClO_2	26.3% (Cl_2)	Generated On-Site
Ozone	O_3	—	Generated On-Site
TASTE AMD ODOR			
Activated Carbon	C	—	Insoluble
Potassium Permanganate	$KMnO_4$	100%	Very Soluble
ALGAE CONTROL			
Copper Sulfate	$CuSO_4 \cdot 5\ H_2O$	99% ($CuSO_4$)	
CORROSION CONTROL			
Calcium Hydroxide (Hydrated Lime)	$Ca(OH)_2$	75-99% (CaO)	Basic
Sodium Hydroxide (Caustic Soda)	NaOH	98.9% (NaOH)	Very Basic
SOFTENING			
Calcium Oxide (Quicklime)	CaO	75-99% (CaO)	
Sodium Carbonate (Soda Ash)	Na_2CO_3	99.4% (Na_2CO_3)	
FLUORIDATION			
Sodium Silico Fluoride	Na_2SiF_6	59.8% (F)	Powder
Sodium Fluoride	NaF	43.6% (F)	Powder or Crystal
Fluosilicic Acid	H_2SiF_6	23.8% (F)	Solution

[a] Adapted from AWWA, Reference 2.

10.53 Safe Handling of Chemicals

In the routine operation of a water treatment plant, you will come in contact with a variety of potentially dangerous chemicals. While some chemicals are inactive (inert), it is good practice to consider *ALL* chemicals as a potential hazard.

When unloading or transferring chemicals, be especially careful. Know the locations of all safety shower and eyewash fountains. Be familiar with their use and test them periodically to be sure that they function properly.

Wear protective clothing when working with chemicals. Goggles and faceshields will protect your eyes and face. Protect other exposed portions of the body by wearing rubber or neoprene gloves, aprons, or other protective clothing. Chemical dust can irritate the eyes and respiratory system. Use respirators when appropriate, and always use dust collectors when such equipment is provided. Promptly wash down or clean up all chemical spills to prevent falls and/or physical contact with the chemical.

A few treatment chemicals such as *CAUSTIC SODA* and *CHLORINE* can be very hazardous to the operator, and extreme care should be taken in the handling of these chemicals. *CAUSTIC SODA* is one of the most dangerous of the common alkalies, and direct contact will cause severe burns. Wash down caustic soda spills immediately. When handling caustic soda, wear safety goggles and a face-shield; cover your head with a wide brim hat; wear rubber or neoprene gloves, apron, and boots (a full body protective suit is preferable); and do not tuck pant legs inside boots or shoes. If dust or mist is encountered, use a respirator.

CHLORINE is a strong respiratory irritant, and either prolonged exposure to chlorine gas or high concentrations of chlorine gas could be *FATAL*. Wherever chlorine liquid or gas are stored or used, the following safety equipment should be provided:

1. Shower and eyewash facility,
2. Emergency breathing apparatus (air pack),
3. Chlorine gas detector,
4. Floor-level vents, and
5. Fans that maintain a positive air pressure in the storage facility. *NOTE:* If you pull air with chlorine through a fan, eventually any wiring or controls in the fan can become corroded and fail.

All water treatment plant operators should be fully trained in chlorine safety and leak detection procedures. Whenever you enter a chlorine facility, make sure that the fan is operating. If a chlorine leak is suspected or the chlorine gas concentration in the room is not known, wear a self-contained air pack and use the buddy system. Rubber- or plastic-coated gloves should be worn when handling chlorine containers. When in doubt — always use the "buddy system" and have another operator standing by with an air pack.

10.54 First Aid Procedures

Every operator should be familiar with the following first aid procedures:

EYE BURNS (GENERAL)

1. Apply a steady flow of water to eyes for at least 15 minutes.
2. Call a physician immediately.
3. *DO NOT* removed burned tissue from the eyes or eyelids.
4. *DO NOT* apply medication (except as directed by a physician).
5. *DO NOT* use compresses.

SKIN BURNS (GENERAL)

1. Remove contaminated clothing immediately (preferably in a shower).
2. Flush affected areas with generous amounts of water.
3. Call a physician immediately.
4. *DO NOT* apply medication (except as directed by a physician).

SWALLOWING OR INHALATION (GENERAL)

1. Call a physician immediately.
2. Read antidote on label of any chemical swallowed. For some chemicals vomiting should be induced, while for other chemicals vomiting should not be induced.

CHLORINE GAS CONTACT

1. If victim is breathing, place on back with head and back in a slightly elevated position. Keep victim warm and comfortable. *CALL A PHYSICIAN IMMEDIATELY.*
2. If breathing has ceased, *IMMEDIATELY* start oral (mouth-to-mouth) resuscitation (artificial respiration). Oxygen should only be administered by *TRAINED* personnel.
3. Eye irritation caused by chlorine gas should be treated by flushing the eyes with generous amounts of water for not less than 15 minutes. Hold eyelids apart to ensure maximum flushing of exposed areas. *DO NOT* attempt to neutralize with chemicals. *DO NOT* apply any medication (except as directed by a physician).
4. Minor throat irritation can be relieved by drinking milk. *DO NOT* give the victim any drugs (except as directed by a physician).

LIQUID CHLORINE CONTACT

1. Flush the affected area with water. Remove contaminated clothing while flushing (preferably in a shower). Wash affected skin surfaces with soap and water while continuing to flush. *DO NOT* attempt to neutralize with chemicals. Call a physician. *DO NOT* apply medication (except as directed by a physician).
2. If liquid chlorine should be swallowed, immediately give victim large amounts of water or milk, followed with milk of magnesia, vegetable oil, or beaten eggs. *DO NOT* give sodium bicarbonate. *NEVER* give anything by mouth to an unconscious victim. Call a physician immediately.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

10.5A What is a pilot plant?

10.5B How are water treatment chemicals stored?

10.5C What protective clothing should be worn when working with chemicals?

10.5D What safety equipment should be provided wherever chlorine liquid or gas are stored or used?

10.6 OPERATING RECORDS AND REPORTS

10.60 Written Documents

As mentioned in previous chapters, one of the most important *ADMINISTRATIVE* functions of the water treatment plant operator is the preparation and maintenance of accurate operational records.

Operating records can be separated into two major categories:

1. Physical records, and
2. Performance records.

PHYSICAL records describe the water treatment plant physical facilities and equipment. These records include:

1. Plant design criteria,
2. Construction plans and contract specifications,
3. "As-built" drawings,
4. Equipment fabrication drawings and specifications,
5. Manufacturers' operation and repair manuals for all equipment items,
6. Detailed piping plans and electrical wiring diagrams,
7. Equipment records including manufacturer's name, model number, rated capacity, and date of purchase,
8. Maintenance records on each equipment item,
9. Hydraulic profiles showing pertinent operating water surface elevations throughout the water treatment plant, and
10. Cost records for all major equipment item purchases and repairs.

PERFORMANCE records describe the operation of the water treatment plant and provide the operator, as well as others, with a running account of plant operations (historical records). These records are a valuable resource for the operator trying to solve current process problems and anticipate future needs. Performance records also provide a factual account of the operation which is required to meet legal and regulatory agency requirements.

Typical performance records include the following:

1. Daily operations records (process production inventory, process changes, process equipment performance — see Figure 10.4);
2. Water quality records (source water, process water, finished water — see Figures 10.5 and 10.6);
3. Equipment failure records;
4. Accident records;
5. Consumer complaint records (include follow-up investigations and corrective actions taken);
6. Chemical inventory records (include storage amounts, safe storage levels, procurement records);
7. Charts produced by process records (strip chart recorders); and
8. Visitor information.

RECORDS MANAGEMENT is a very important part of the overall recordkeeping process. Records should be filed and cataloged or indexed for future reference. Regulatory agencies may require you to keep certain water quality analyses (bacteriological test results) and customer complaint records on file for specified time periods (10 years for chemical analyses and bacteriological tests). Other records may have historical value to the operator (source water quality changes and resultant process changes). These records should be maintained in appropriate files properly labeled for easy reference. In addition, a daily diary or pocket notebook should be used by each operator to record unique or unusual events. A typical entry that might appear in an operator's diary or daily operating log is as follows:

8:30 a.m.
Raw water pump No. 1 starting to develop a whine during low flows.
JQO (operator should initial entry)

10.61 Oral Communications

In the previous section we described the types of written documents that the operator uses to assist in the operation of a water treatment plant and to account for the daily operation. In addition to these written records and reports, to perform effectively you will need to orally communicate with other operators as well as supervisory and other staff personnel.

Most organizations have a "chain-of-command" established which describes the individuals that you must communicate with and establishes levels and lines of authority.

You must realize that communications are always "two-way," regardless of the size of the organization. There are more people to communicate with in larger organizations. The successful operation of a water treatment plant depends to a large degree on good oral communications. Regardless of plant size, everyone involved must realize that plant operation is not a "one-operator" show.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 451.

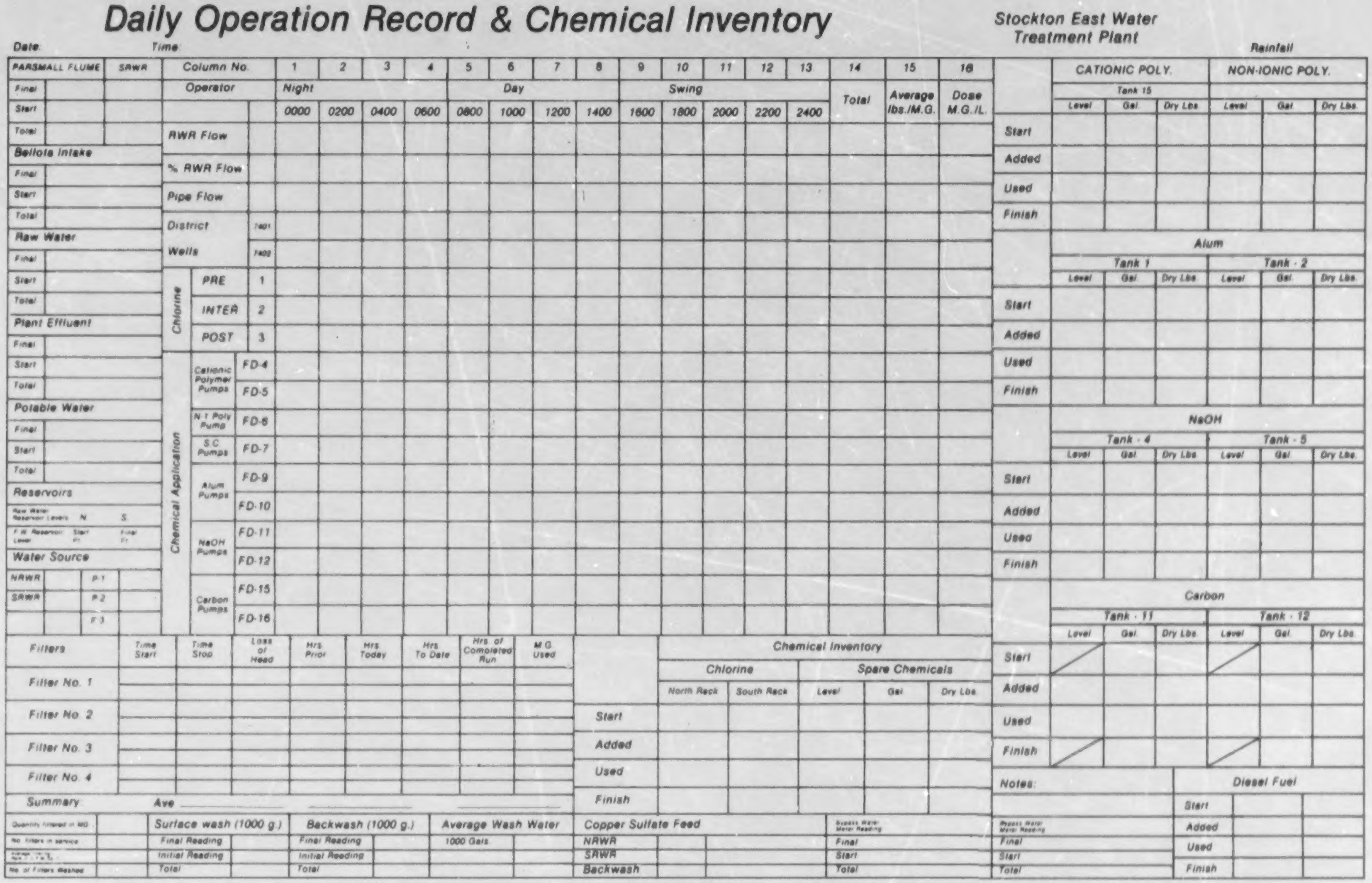
10.6A What are the two major categories of operating records?

10.6B What are performance records?

10.6C What records may have great historical value to the operator?

10.6D Why should each operator use a pocket notebook?

End of Lesson 1 of 2 Lessons on PLANT OPERATION



Daily Operation Record & Chemical Inventory

Stockton East Water
Treatment Plant

Date:
Time:
Rainfall

PARSMALL FLUME		SRWR
Final		
Start		
Total		
Bellota Intake		
Final		
Start		
Total		
Raw Water		
Final		
Start		
Total		
Plant Effluent		
Final		
Start		
Total		
Potable Water		
Final		
Start		
Total		
Reservoirs		
Raw Water Reservoir Levels	N	S
F.W. Reservoir Level	Start Ft	Final Ft
Water Source		

NRWR		P-1	
SRWR		P-2	
		P-3	

Column No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Operator		Night				Day				Swing					Total	Average lbs./M.G.	Dose M.G./L.
		0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200	2400			
RWR Flow																	
% RWR Flow																	
Pipe Flow																	
District	7401																
Wells	7402																
Chlorine PRE	1																
Chlorine INTER	2																
Chlorine POST	3																
Chemical Application Cationic Polymer Pumps	FD-4																
	FD-5																
N-1 Poly Pump	FD-6																
S.C. Pumps	FD-7																
Alum Pumps	FD-9																
	FD-10																
NaOH Pumps	FD-11																
	FD-12																
Carbon Pumps	FD-15																
	FD-16																

	CATIONIC POLY.			NON-IONIC POLY.		
	Tank 15					
	Level	Gal	Dry Lbs.	Level	Gal	Dry Lbs.
Start						
Added						
Used						
Finish						

	Alum					
	Tank 1			Tank - 2		
	Level	Gal	Dry Lbs.	Level	Gal.	Dry Lbs.
Start						
Added						
Used						
Finish						

	NaOH					
	Tank - 4			Tank - 5		
	Level	Gal.	Dry Lbs.	Level	Gal	Dry Lbs.
Start						
Added						
Used						
Finish						

	Carbon					
	Tank - 11			Tank - 12		
	Level	Gal.	Dry Lbs.	Level	Gal.	Dry Lbs.
Start						
Added						
Used						
Finish						

Filters	Time Start	Time Stop	Loss of Head	Hrs. Prior	Hrs. Today	Hrs. To Date	Hrs. of Completed Run	M.G. Used
Filter No. 1								
Filter No. 2								
Filter No. 3								
Filter No. 4								
Summary	Ave							

	Chemical Inventory				
	Chlorine		Spare Chemicals		
	North Rack	South Rack	Level	Gal	Dry Lbs.
Start					
Added					
Used					
Finish					

Notes:

Diesel Fuel		
Start		
Added		
Used		
Finish		

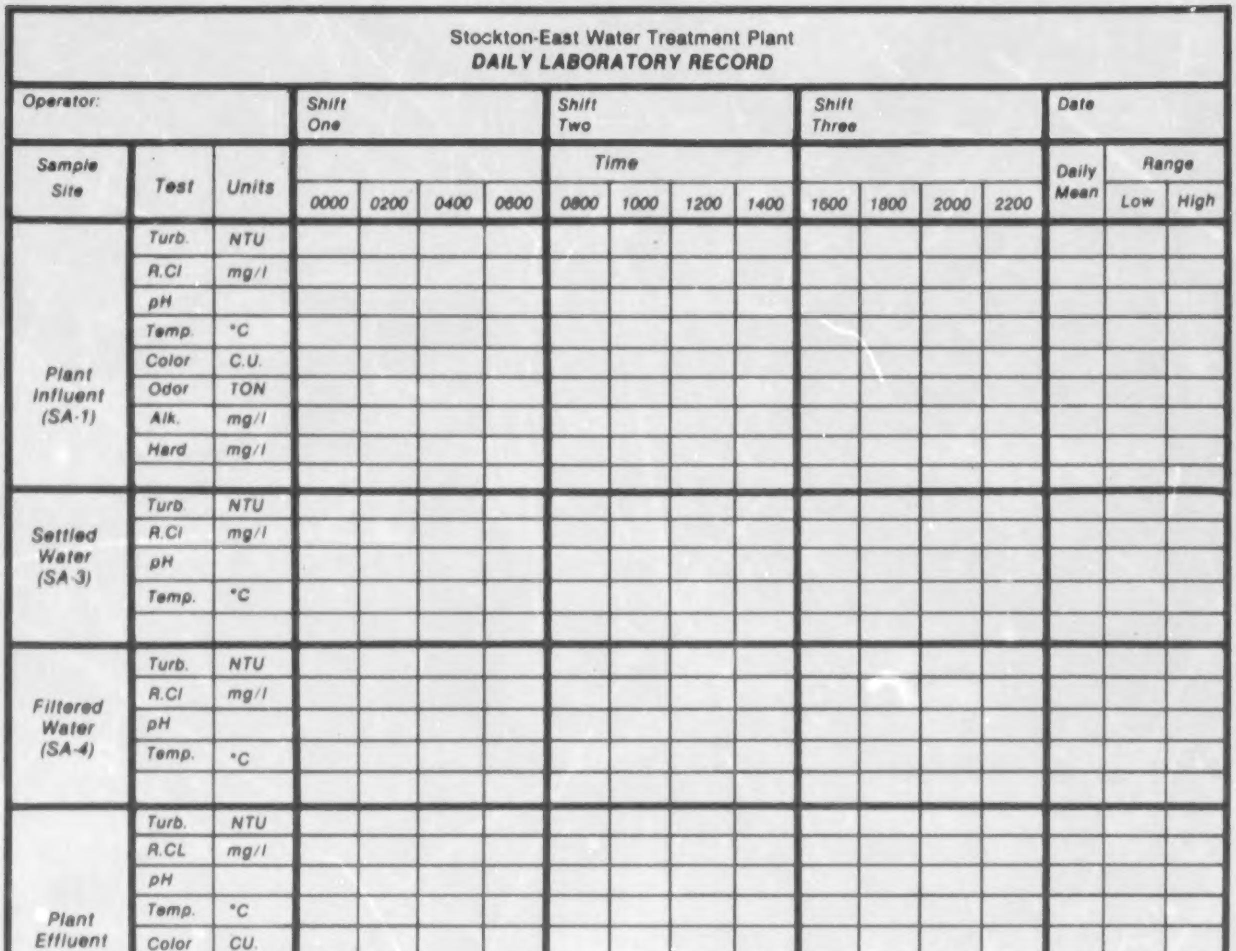
		Surface wash (1000 g.)		Backwash (1000 g.)		Average Wash Water	
Quantity filtered in MG		Final Reading		Final Reading		1000 Gals.	
No. filters in service		Initial Reading		Initial Reading			
Average [illegible]		Total		Total			
No. of Filters Washed							

Copper Sulfate Feed		
NRWR		
SRWR		
Backwash		

Bypass Water Meter Reading	
Final	
Start	
Total	

Bypass Water Meter Reading	
Final	
Start	
Total	

Fig. 10.4 Daily operation record and chemical inventory



Stockton-East Water Treatment Plant
DAILY LABORATORY RECORD

Operator:	Shift One	Shift Two	Shift Three	Date

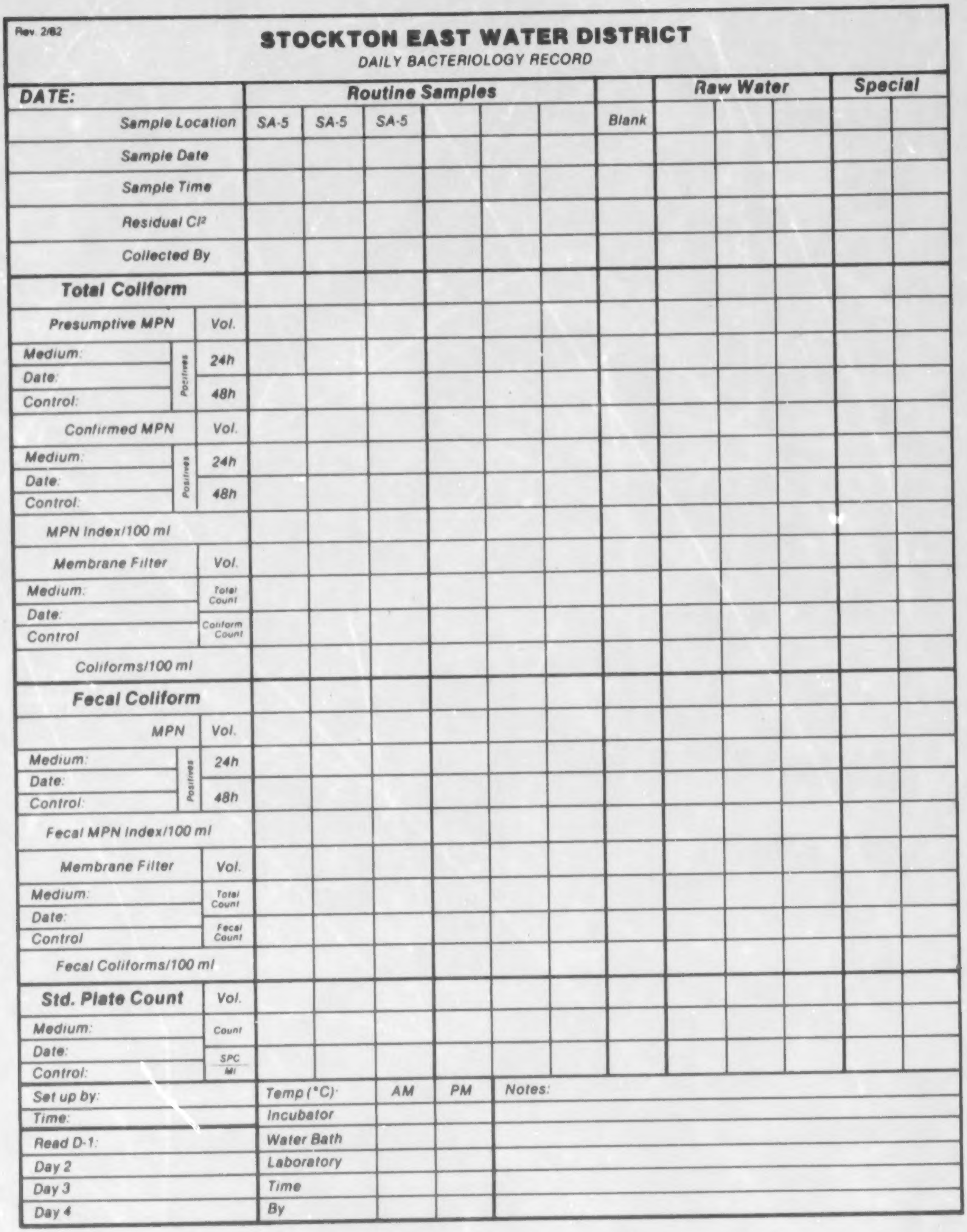
Sample Site	Test	Units					Time								Daily Mean	Range	
			0000	0200	0400	0600	0800	1000	1200	1400	1600	1800	2000	2200		Low	High
Plant Influent (SA-1)	Turb.	NTU															
	R.Cl	mg/l															
	pH																
	Temp.	°C															
	Color	C.U.															
	Odor	TON															
	Alk.	mg/l															
	Hard	mg/l															
Settled Water (SA-3)	Turb.	NTU															
	R.Cl	mg/l															
	pH																
	Temp.	°C															
Filtered Water (SA-4)	Turb.	NTU															
	R.Cl	mg/l															
	pH																
	Temp.	°C															
Plant Effluent (SA-5)	Turb.	NTU															
	R.CL	mg/l															
	pH																
	Temp.	°C															
	Color	CU.															
	Odor	TON															
	Alk.	mg/l															
	Hard.	mg/l															
	Flow	MGD															

Plant Flow			Polymer		Alum		NaOH		Chlorine						PAC		Sp. Chem	
									Pre		Inter		Post					
Time	MGD	Source	Time	mg/l	Time	mg/l	Time	mg/l	Time	lb/D	Time	lb/D	Time	lb/D	Time	mg/l	Time	mg/l

Remarks:

Rev. 3/82

Fig. 10.5 Daily laboratory record



Rev. 2/82

STOCKTON EAST WATER DISTRICT

DAILY BACTERIOLOGY RECORD

DATE:		**Routine Samples**							**Raw Water**			**Special**	
Sample Location		SA-5	SA-5	SA-5				Blank					
Sample Date													
Sample Time													
Residual Cl^2													
Collected By													
Total Coliform													
Presumptive MPN	Vol.												
Medium:	Positives 24h												
Date:													
Control:	48h												
Confirmed MPN	Vol.												
Medium:	Positives 24h												
Date:													
Control:	48h												
MPN Index/100 ml													
Membrane Filter	Vol.												
Medium:	Total Count												
Date:													
Control	Coliform Count												
Coliforms/100 ml													
Fecal Coliform													
MPN	Vol.												
Medium:	Positives 24h												
Date:													
Control:	48h												
Fecal MPN Index/100 ml													
Membrane Filter	Vol.												
Medium:	Total Count												
Date:													
Control	Fecal Count												
Fecal Coliforms/100 ml													
Std. Plate Count	Vol.												
Medium:	Count												
Date:													
Control:	SPC/Ml												

Set up by:	Temp (°C):	AM	PM	Notes:
Time:	Incubator			
Read D-1:	Water Bath			
Day 2	Laboratory			
Day 3	Time			
Day 4	By			

Fig. 10.6 Daily bacteriology record

DISCUSSION AND REVIEW QUESTIONS

Chapter 10. PLANT OPERATION

(Lesson 1 of 2 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions which you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook before continuing.

1. What are the three basic objectives of operating a water treatment plant?
2. Why are water quality standards measured at the consumer's tap?
3. How frequently should samples be collected for process control?
4. What is the purpose of a clear well?
5. How are the initial selection of chemical types and anticipated feed rates for a given application in a water treatment plant usually determined?
6. What precautions would you take when handling caustic soda?
7. Why are positive air pressure fans preferred over floor-level exhaust fans in chlorine storage facilities?
8. How long should records be kept?

Chapter 10. PLANT OPERATION

(Lesson 2 of 2 Lessons)

10.7 PLANT MAINTENANCE

10.70 Maintenance Program

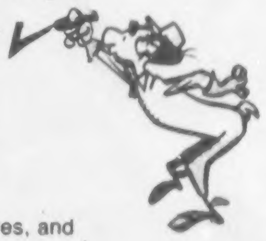
10.700 Responsibility

The water treatment plant maintenance program is an important part of plant operations. The overall maintenance program should be designed to assure continuing satisfactory operation of the treatment plant facilities under a variety of different operating conditions. Such a program would include routine and preventive maintenance as well as provisions for effectively handling emergency breakdowns.

All plants should have written instructions on how to operate and maintain the equipment. If your plant does not have written instructions, prepare them now or budget the necessary funds to have someone prepare them. These instructions are very helpful when someone retires or leaves and a new operator is assigned these duties.

The major elements of a good preventive maintenance (P/M) program include the following:

1. Planning and scheduling,
2. Records management,
3. Spare parts management,
4. Cost and budget control,
5. Work order system,
6. Emergency repair procedures, and
7. Training program.



10.701 Planning and Scheduling

Planning and scheduling is the backbone of the maintenance program. An important source of information for planning routine maintenance is equipment manufacturers' operating and maintenance instructions. These instructions are usually furnished with the equipment at the time of purchase, or can be obtained directly from the manufacturer. Another important reference source is the plant "Operation and Maintenance Instructions."

The planning and scheduling effort should define the specific maintenance tasks to be done and the time intervals. The following items are important considerations in developing a good maintenance plan:

1. Skills needed,
2. Special tools and equipment requirements,
3. Parts availability,
4. Routine procedures (lubrication), and
5. Special procedures (equipment overhaul).

10.702 Records Management

Good records management is an important administrative feature of the maintenance program and one that is often overlooked. A comprehensive records management system provides the basis for daily task assignments, provides a permanent record of work performed, and becomes a historical reference source for reviewing equipment performance.

The following records should be maintained as a part of a good records management system:

1. Equipment inventory cards,
2. Preventive maintenance schedules,
3. Spare parts lists and reorder information, and
4. Records of work performed.

10.703 Spare Parts Management

Certain parts of mechanical equipment items, such as shaft bearings, require periodic replacement because they have a useful life which is considerably shorter than the predicted overall equipment life. This requires that an adequate stock of spare parts be kept on hand at the treatment plant to facilitate planned replacement.

Spare parts should be stocked on the basis of the:

1. Importance of the part to operation,
2. Availability,
3. Effect on operation if part is defective, and
4. Storage space.

If a part is readily available from a supplier, let the supplier stock it for you. It costs money to stock and warehouse unnecessary spare parts. The actual performance history of a particular piece of equipment may indicate the type and number of spare parts that must be stocked. Spare parts should be promptly reordered whenever they are used.

10.704 Cost and Budget Control

Accurate records of labor and equipment expenditures are an important part of the overall budget and cost control program. Operation and maintenance budgets are usually prepared on an annual basis. A thorough and up-to-date written performance history of equipment operations, repair, and replacement costs will significantly improve the budget planning process. These records will also provide valuable information for deciding when to replace a given piece of equipment due to excessive repair costs.

10.705 Emergency Repair Procedures

Identify those pieces of equipment which are critical for your facility to meet the demands for safe drinking water of your consumers. Critical pieces of equipment include raw water pumps, chlorinators and pumps which deliver finished water to the distribution system. All of these items must have standby or back up equipment. Also your plant should have standby generators in case of a power outage. If any of these facilities fail, you must have emergency repair procedures to follow which will enable you to put your facility back in service as soon as possible.

10.706 Work Order System

The work order system is a way of keeping track of how much time and money is spent doing various types of work. This information becomes a planning tool and a reporting system to indicate what is being done and how much it costs. This procedure records the parts used in the repairs and the amount of labor required to perform the repair or other maintenance procedures, as well as other kinds of work.

10.71 Routine Equipment Inspection

In the routine operation of the water treatment plant, the operator will inspect various mechanical equipment items (valves, pumps) and electrical equipment items (motors) to check for proper operation, and will perform a number of maintenance functions as follows:

1. Keep motors free of dirt and moisture,
2. Assure good ventilation (air circulation) in equipment work areas,
3. Check motors and pumps for leaks, unusual noise, vibrations, or overheating,
4. Maintain proper lubrication and oil levels,
5. Check for alignment of shafts and couplings,
6. Check bearings for overheating and proper lubrication,
7. Check for proper valve and pump operation, and
8. Check calibration of chemical feeders.

These tasks should generally be performed on a daily basis.

For details on how to develop a maintenance program, see Chapter 18, "Maintenance."

10.72 Need for Proper Tools

In order to be effective in the routine maintenance of plant equipment, you will need to know how to properly use common hand tools in order to protect equipment and for your own safety. Remember that you cannot perform maintenance procedures safely and properly if you do not have the proper tools.

The exact tools each operator should be familiar with is difficult to specify since the maintenance performed by a plant operator will vary considerably depending on the size of the treatment plant and the number of operators. In larger plants, maintenance personnel will perform virtually all of the routine as well as specialized maintenance functions. In smaller plants the operator will be expected to perform most of the routine maintenance functions.

You should be familiar with the following types of common hand tools:

1. Screw drivers (slotted and phillips),
2. Pipe wrenches,
3. Crescent wrenches,
4. Socket wrenches,
5. Allen wrenches,
6. Open-end and box wrenches,
7. Hammers (claw, sledge, mallet),
8. Pliers,
9. Vice-grips,
10. Files,

11. Wire brushes, and
12. Putty knives.

Tool loss and replacement can be a problem at any water treatment plant unless procedures are implemented to effectively manage the inventory of tools and equipment. A commonly used procedure is the simple "check-out list." An individual desiring to use a special tool merely signs out for the tool, listing the type of tool, date, and name or initials. When the tool is returned the name is simply struck off the list. Simple 3" x 5" or 5" x 7" cards can be used for this purpose. A simple color coded tag system may also prove useful for keeping track of tools.

In the event that a tool is lost or damaged, the description of the tool and any special circumstances or information should be noted so that it can be repaired or replaced.

For an additional list of tools used by operators, see *WATER SUPPLY SYSTEM OPERATION*, Chapter 4, "Small Water Treatment Plants," in this series of manuals.

10.73 Training Program

Perhaps as important as any other single element of the operation and maintenance program is training. Training should be an on-going feature of the operation program and operators should be encouraged to participate. Such training can increase the expertise of maintenance and operations personnel in the general repair of equipment, in specialized procedures required to calibrate and repair selected equipment items, and in their ability to quickly and properly respond to changes in raw and finished water.

Major equipment manufacturers periodically conduct training programs designed to provide operations and maintenance personnel with a "hands-on" familiarity with common mechanical and electrical equipment items.

The certification requirements in most states require successful completion of some form of education or training to qualify for taking a certification examination. In some states some type of education requirement must be met before a certificate can be renewed. In order to do a good job, people need an opportunity to improve their knowledge and skills. The best way for people to improve themselves is with a well-planned training program.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.7A List the major elements of a good preventive maintenance program.

10.7B Why is a records management system important?

10.7C What items should be included in a cost and budget control program?

10.8 PLANT SAFETY AND SECURITY

10.80 Safety Considerations

In the routine operation of the water treatment plant, the operator will be exposed to a number of potential hazards including:

1. Electrical equipment (shocks),
2. Rotating mechanical equipment,
3. Water treatment chemicals (acids, alkalies, chlorine gas),
4. Laboratory reagents (chemicals),
5. Open-surface, water-filled structures (drowning),
6. Underground structures (toxic and explosive gases, lack of oxygen), and
7. Pump stations (high noise levels).

Ample safety devices are generally provided at each water treatment plant to protect the operator, as well as others, from accidents and exposure to chemicals, dust, and other hazardous environments. However, these safety devices are of limited value unless you pay strict attention to safety procedures. If an object appears too heavy to lift, do not try to lift it. Get help or use a lifting device such as a fork lift.

When working around mechanical and electrical equipment, plant structures, or chemicals, follow the safety procedures listed below to avoid accidents or injury.

ELECTRICAL EQUIPMENT

1. Avoid electrical shock by using protective gloves.
2. Avoid grounding yourself in water or on pipes.
3. Ground all electrical tools.
4. Lock out electrical circuits and tag out remote controls when working on equipment.
5. Always assume all electrical wires are "live."
6. Never use metal ladders around electrical equipment.
7. When in doubt about a procedure or repair, ask for help.
8. Use the buddy system and be sure your buddy knows how to rescue you when you need help.

MECHANICAL EQUIPMENT

1. Do not remove protective guards on rotating equipment.
2. Do not wear loose clothing around rotating equipment.
3. Secure and lock out drive motors before working on equipment. Tag out remote controls.
4. Clean up all lubricant spills (oil and grease).

OPEN-SURFACE WATER-FILLED STRUCTURES

1. Do not avoid or defeat protective devices such as handrails by removing them when they are in the way.
2. Close all openings when finished working.
3. Know the location of all life preservers.

UNDERGROUND STRUCTURES AND CONFINED SPACES

1. Know the condition of the environment before entering. Determine if there are any toxic gases present, explosive conditions or a lack of oxygen. Use detection devices which are capable of monitoring the atmosphere continuously.
2. Use portable ventilation fans to assure good air circulation.
3. Use the buddy system. Also be certain your buddy is trained and knows what to do in the event that you get into trouble.

CHEMICALS

1. Wear protective clothing when handling or unloading chemicals.
2. Wear goggles and faceshields around all potentially hazardous chemicals.
3. Know the location of all safety shower and eyewash facilities (be sure they work).
4. Be familiar with the care and use of air packs.
5. Know chlorine leak detection and safe handling procedures.
6. Promptly clean up all chemical spills.

If a hazardous situation exists or if a particular procedure is unsafe, do not proceed — call for help.

Always be sure to report any injury, no matter how slight, to your immediate supervisor. This procedure protects you as well as your employer.

For details on how to develop a safety program and safety procedures, see Chapter 20, "Safety."

10.81 Security Considerations

Public access to water treatment plant facilities and grounds can result in vandalism or injury of trespassers or other unwanted visitors. In addition, never rule out the potential for sabotage of a facility, such as a water treatment plant. The public water supply affects the entire community.

Fences and gated accesses help to discourage trespassers and other unwanted visitors from entering treatment plant grounds and facilities. Gates should be securely locked during "non-routine" working hours and, in some instances, automatic remotely controlled gates may be required to limit access during all hours of operation. Routinely inspect the plant facilities (at least once per shift) and report any unusual persons or events to the proper authorities.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.8A List the potential hazards an operator could be exposed to during the routine operation of a water treatment plant.

10.8B How often should an operator routinely inspect plant facilities for any evidence of unusual persons or events?

10.9 EMERGENCY CONDITIONS AND PROCEDURES

10.90 Emergency Conditions

In the operation of any water treatment plant, abnormal or emergency conditions will occasionally arise which require calm, quick action on the part of the operator. Emergency conditions you may encounter include:

1. Treatment process failures,

2. Process equipment failures,
3. Power failures,
4. Fires, and
5. Floods, earthquakes, or other natural disasters.

You must be able to distinguish between an abnormal condition and a "red alert" emergency condition. *A "RED ALERT" MEANS THAT YOU MUST IMMEDIATELY SEEK OUTSIDE HELP.* Typical red alert emergencies include raw water contamination, chemical spills, fires, serious injury, and a chlorine leak.

10.91 Treatment Process Failures

10.910 Changes in Raw Water Quality

Treatment process failures generally result from an abrupt or unexpected change in source water quality. A typical example of this condition occurs when the source water suspended solids concentration abruptly increases (high turbidity) as a result of precipitation and runoff into the source water supply. Other, less common, examples are accidental wastewater contamination or chemical spills in the source water system.

Turbidity fluctuations resulting from precipitation and runoff should be anticipated by the operator, and every effort should be made to obtain samples of the water for jar testing just as soon as possible. This will allow the operator to make planned adjustments to the treatment process and avoid major process upsets.

Contamination of the source water system by wastewater or chemical spills is nearly impossible to anticipate, so planned adjustments to the treatment process to correct for these problems is unlikely. However, an early warning of wastewater contamination of the source water may be a sudden drop in chlorine residual in the treatment process or a sudden increase in the chlorine demand of the water being treated. Immediate adjustment of the chlorine dosage should be made and additional bacteriological tests should be performed to define the extent of the problem. Don't wait for the results from bacteriological tests to tell you that you have a problem because by then it is too late.

Accidental chemical spills are perhaps the most hazardous situation to deal with, since normal treatment process monitoring techniques may not detect the problem. In most cases, the operator must rely on outside notification of this event. Special sampling may be required to define the extent of the problem.

In cases where a treatment process upset results in the failure to meet a specific water quality standard, the operator must promptly notify supervisory personnel and the appropriate local health authorities. In extreme cases, complete process shutdown and/or public notification may be required. During these periods, the operator must work closely with health authorities.

10.911 *Operator Error*

Occasionally all of us make a mistake. If we are on top of everything and operating our plant as intended, an error in one process may be eliminated or reduced by another process.

Proper chemical doses can be difficult to maintain. If you discover the chemical dose is too high or too low, immediately make the proper adjustment. Try to monitor the doses more frequently.

If you discover insufficient or no chlorine residual in your clear well, immediately increase the chlorine dosage to the finished water. Review your records. If everything is working properly, all of your quality control tests are looking good, and the turbidity level in the clear well is low, you probably will experience no serious problems.

However, if you discover no chlorine residuals in your clear well and your plant is having operating difficulties, you are in trouble. If the turbidity is high in the clear well, try to add chlorine to the clear well or to the finished water pump discharge to achieve the desired chlorine residuals in the clear well and through the entire distribution system. Review your records and the operation of your chlorination system. Determine why there is no chlorine residual in the clear well and correct the situation.

Unfortunately errors can and do happen. After an error has occurred, try to develop procedures which will prevent the error from occurring again. Share your experience with other operators so they won't make the same error. Working together is important and can help everyone.

10.92 Process Equipment Failures

Process equipment failures may also result in treatment process upsets in the event that chemical feeders, chlorinators, or other primary process equipment items fail to operate satisfactorily. The best safeguard against premature process equipment failures is a good preventive maintenance program. The operator plays a vital role in the preventive maintenance program by performing daily inspections of process equipment and making minor adjustments and repairs when necessary.

In certain essential processes such as in chlorination systems, extra equipment is usually built into the system to provide backup in case an individual system part fails. This feature should also be included in other primary process systems such as chemical feed systems.

In the event of a process failure that results in the failure to meet a water quality standard, promptly notify supervisory personnel and the appropriate local health authorities. In extreme cases, process shutdown and/or public notification may be necessary. Let's examine possible equipment failures and how you might respond to them. We are assuming that you don't have standby facilities or they have failed too. If you consider what would happen at your plant if these failures occur, you may be able to justify the installation of essential standby equipment.

1. Intake screens

   If intake screens become plugged or broken. Shut the plant down and unplug or repair the screens. Standby or alternate screens obviously are essential. A bypass system may allow continuous operation and avoid the need to shut down the plant.

2. Grit basin

   Mechanical collector fails and can't be corrected or adjusted by above-water repair procedures. Whenever facilities must be dewatered for emergency repairs, try to fill up all water storage facilities by early evening. Dewater facility and repair at night when demands are low.

3. Prechlorination

   a. Shut down facilities and repair immediately. Try to avoid allowing unchlorinated water to pass through your plant and having to rely solely on postchlorination.

   or

   b. If postchlorination facilities are adequate, you may wish to rely strictly on postchlorination. Under these conditions, increase surveillance of chlorine residuals.

4. Alum or polymer feeder

   Shut down influent pumps. Repair chemical feeder. Do not allow water to flow past point of chemical applica tion without alum or polymer. Otherwise, turbidity will pass through filters and may exceed EPA Primary Drinking Water Standards.

5. Rapid mix or flash mix

   Consider moving point of chemical application to a location where water turbulence can help to achieve hydraulic mixing.

6. Flocculators

   a. Underwater. Wait until scheduled dewatering of facility and then repair.

   b. Mechanical. Repair as soon as possible.

7. Sedimentation tank

   Mechanical sludge collector fails and can't be repaired or adjusted by above-water procedures. Dewater facility and repair at night when demands are low.

8. Filters

   Valve or backwash system fails. Take failed portion (bank) out of service and repair.

9. Postchlorination

   a. Increase prechlorination doses if possible.

   or

   b. If you are using postchlorination only, shut down and repair immediately. Notify supervisors and proper authorities.

10. Corrosion control chemicals

    Repair as soon as possible.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.9A What three factors usually cause treatment process failures?

10.9B How would you safeguard against premature process equipment failures?

10.9C What would you do if the prechlorination facility in your plant failed?

10.93 Power Failures

A backup electrical power source is usually provided at water treatment plants for use in the event of commercial power failure. Engine-generator sets powered by diesel fuel, natural gas, or liquid petroleum gas, provide the standby capability to furnish a limited amount of electrical power to keep the water treatment plant in service during periods of commercial power failure. In most cases, it is not practical to provide emergency power to meet all treatment plant demands. Therefore, only critical process functions (such as chemical feeders, mixers, flocculators, and process pumps) are included on the emergency power buss. This power buss is usually connected to primary process equipment items by a transfer switch that automatically transfers power to the backup or standby source during failures.

At the onset of a commercial power failure, take the following actions:

1. Notify the commercial power supplier of the outage;
2. If the power failure originated at the treatment plant, notify electrical maintenance personnel immediately;
3. Restart process equipment that shut off during the power failure. (Prepare a sequence for your plant so that only one piece of equipment at a time is restarted to avoid overload.);
4. Check chlorination equipment and safety devices for proper operation;
5. Check the engine-generator set for proper operation;
6. Notify supervisory personnel of the condition; and
7. Visually inspect all process equipment and check the performance of unit treatment processes.

During brief periods of power outage, most primary plant process functions can continue to operate. However, for extended periods of power outage, it may be necessary to reduce plant production since filter backwashing systems are usually not connected to the emergency power buss due to the high energy demand. As filters stop working due to head loss buildup or turbidity breakthrough, they should simply be removed from service. If insufficient clean filters are available to replace them, the plant flow rate will have to be reduced.

When commercial power is restored, take the following actions:

1. Restart process equipment that shut off during the transfer or was off-line during the outage (one at a time),
2. Backwash dirty filters and return them to service,
3. Increase plant flow rate as appropriate,
4. Visually inspect all process equipment and performance of unit treatment processes,
5. Verify process and treated water quality, and
6. Notify supervisory personnel of conditions.

10.94 Fires

If a fire occurs at the water treatment plant, immediately notify the local fire department and then determine the source of the fire. Depending on the type of fire (structure, chemical, electrical), you should use the appropriate fire safety equipment available at the plant in an attempt to extinguish the fire. *DO NOT* try to be a hero! If the fire is too involved, wait for the fire department to arrive (response time is usually short).

After calling the fire department, notify plant supervisory personnel promptly of the emergency condition at the plant.

If you have not already done so, make yourself thoroughly familiar with the care and use of fire safety equipment and learn the special procedures to be observed in dealing with chemical and electrical fires. You won't have time to study the equipment after a fire starts.

10.95 Natural Disasters

Fortunately, natural disasters such as floods and earthquakes are relatively rare events. Most water treatment plants are designed with these events in mind and adequate safety features are usually built into the plant to minimize damage caused by floods or earthquakes. Water treatment plants are normally located on sites that are above the standard flood plain, or special measures are taken to prevent facilities from flooding during a heavy rainstorm.

Emergency preparedness and earthquake safety in the design of new structures are very important. Since there is not much that operators, or anyone else, can do during catastrophic events, only additional planning and emergency preparation will help protect water supplies.

Following any major flood, earthquake, or other natural disaster, take the following actions:

1. Inspect accessibility of all facilities,
2. Check condition and function of all process equipment,
3. Check structures and chemical storage tanks for structural or other damage,
4. Check the plant piping system for leaks or other visual signs of damage,
5. Prepare a preliminary damage report, and
6. Report conditions to plant supervisory personnel.

10.96 Communications

In the event of an emergency, you will be required to advise other plant personnel of the conditions which exist or events which have occurred.

An *EMERGENCY RESPONSE PROCEDURE* should be developed for every water treatment plant so that notification of the proper personnel can be readily accomplished and the emergency resolved. Emergency response procedures should list the *NAMES AND TELEPHONE NUMBERS* of persons to be notified under specified conditions, including health department authorities. Guidelines should be developed to assist the operator in determining when to implement these procedures. Alternate communication methods must be considered because telephone service may be lost during an emergency.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.9D What happens at most water treatment plants when commercial power fails?

10.9E What would you do if a fire occurred at your water treatment plant?

10.9F After a major flood, what action should be taken by a water treatment plant operator?

10.10 SLUDGE HANDLING AND DISPOSAL

10.100 Discharge Standards

The problem of water treatment plant sludge disposal is very important. Federal laws include sludge from a water treatment plant as an industrial waste and require proper handling and disposal. Under the National Pollutant Discharge Elimination System (NPDES) provision of the federal laws, a permit must be obtained for wastewater discharge (process sludge) from a water treatment plant into a surface water or groundwater source. This permit sets discharge limits on water quality characteristics such as pH, total suspended solids, settleable solids, flow, and *BOD*.[3]

10.101 Sludge Sources

Suspended solids in the source water represent the major source of sludge solids to be disposed of as a result of water treatment. The treatment chemicals themselves, especially alum, constitute a secondary source of sludge solids. Another major source of sludge is the precipitate from the lime-soda ash softening process.

In most water treatment plants, over 99 percent of the suspended solids in the source water are removed by the sedimentation and/or filtration processes. These processes concentrate the source water solids and treatment chemicals which are then collected and processed to reduce their volume before final disposal.

10.102 Sludge Processing and Disposal

For procedures on how to process and dispose of sludge, see Chapter 17, "Handling and Disposal of Process Wastes," in Volume II. Another helpful reference is *OPERATION OF WASTEWATER TREATMENT PLANTS*, Volume III, Chapter 22, "Solids Handling and Disposal." This publication is available from Ken Kerri, Foundation of California State University, Sacramento, 6000 J Street, Sacramento, CA 95819. Price, $30.00

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.10A What do the letters NPDES stand for?

10.10B How are most suspended solids in the source water removed at water treatment plants?

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[3] *BOD (pronounce as separate letters). Biochemical Oxygen Demand. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.*

10.11 HANDLING WATER QUALITY COMPLAINTS

10.110 Guidelines for Handling Complaints

No discussion of water treatment plant operation would be complete without discussing consumer complaints, investigation procedures, and possible causes for complaints. The following guidelines and procedures are taken from "Procedural Manual for Handling Water Quality Complaints," prepared by the System Water Quality Committee, California-Nevada Section, American Water Works Association.

Some basic guidelines that should be followed in dealing with consumer complaints are listed below:

1. Be friendly and courteous to the consumer at all times,
2. Assure the consumer that you are pleased that they have taken the trouble to call about their problem,
3. Ask the consumer to describe the problem,
4. Listen carefully and calmly to the consumer's explanation,
5. Review with the consumer the explanation of the problem and ask questions as required to make certain you understand the problem,
6. Do not argue with the consumer,
7. Make every effort to give the consumer an immediate, clear, and accurate answer to the problem,
8. If it is necessary to contact the consumer at their place of business or residence, assure them that it will be scheduled as soon as possible,
9. Do your best to assure the consumer that the problem has been or will be resolved, and
10. If the consumer cannot be satisfied, offer to refer the person to someone in management.

Remember, it is often consumer complaints that alert you to developing problems of water quality or service.

10.111 Investigating Complaints

In some instances, it will be possible to resolve the consumer's problem over the telephone. In many instances, however, it is best to dispatch operators into the field to determine the cause of the condition. Tables 10.7 through 10.14 describe the more common types of consumer complaints, investigation procedures, and possible causes for complaints.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.11A List the common types of consumer complaints.

10.11B What could be done to solve a consumer's complaint that there is air in the water?

10.11C What would you do if a consumer complained that the drinking water was causing a sickness?

10.12 ENERGY CONSERVATION

10.120 Energy Considerations

In the operation of a water treatment plant, a considerable amount of energy may be consumed for lighting, heating and air-conditioning, and powering numerous electrical motors located throughout the plant. Operators can have a positive impact on overall treatment plant operating costs if energy conservation procedures are followed on a routine basis.

10.121 Energy Conservation Procedures

LIGHTING usually represents less than five percent of the electrical energy use in a water treatment plant. Even though this is a small percentage, positive measures can be taken to reduce these costs as follows:

1. Turn lights off when leaving a room or work area,
2. Turn lights off in unoccupied areas,
3. Limit yard lighting to essential areas,
4. Replace existing lamps with high efficiency lamps as the old ones burn out or require replacing, and
5. Convert mercury vapor lamps to more efficient high pressure sodium vapor lamps.

HEATING, VENTILATING, AND AIR CONDITIONING equipment consume substantial amounts of fuel and electrical energy. Energy savings can be gained here by simply adjusting thermostats to more efficient settings. Thermostats should be set at 78°F (26°C) for cooling, and at 68°F (20°C) for heating.

ELECTRIC MOTORS consume the greatest amount of electricity in most water treatment plants, over 90 percent of total electrical energy consumed. Considerable savings can be achieved by replacing old electric motors with high efficiency motors as the old ones burn out.

Consideration should also be given to installing capacitors at the treatment plant to correct a low plant *POWER FACTOR*.[4] Capacitors offset the reaction power used by inductive devices (electric motors) and improve the overall power factor of the plant. This can result in considerable energy savings

10.122 Power Management

The most sophisticated approach to energy conservation, and perhaps the most beneficial, is through a power management program. A power management program starts by identifyng each source of energy use in the water treatment

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[4] *Power Factor. The ratio of the true power passing through an electric circuit to the product of the voltage and amperage in the circuit. This is a measure of the lag or load of the current with respect to the voltage.*

TABLE 10.7 AIR AND/OR MILKY WATER

COMPLAINT INVESTIGATION	POSSIBLE CAUSES FOR COMPLAINT
1. *INFORMATION NEEDED*	1. *DISTRIBUTION SYSTEM*
What is location of premises?	Shutdown of mains
Determine pressure zone of consumer's premises.	Low pressure in mains
Are the premises new, or has some new galvanized pipe been installed recently?	Leaking pump glands
When was air or milkiness first noticed?	Temperature changes in water
Has the water to the premises been shut off recently?	Cross-connections
Is the air or milkiness in both the hot and cold water?	Miscellaneous causes
2. *FIELD INVESTIGATION*	2. *PRIVATE PLUMBING SYSTEM*
Check water at consumer's premises.	Overheating of hot water systems
Eliminate air in water by:	Warming up of cold water lines
(a) Flush house lines if necessary.	Zinc from galvanized pipe
(b) Flush hydrants or blowoffs if necessary.	Cross-connections
Take sample to laboratory if necessary.	Miscellaneous causes
Report results of laboratory tests to consumer.	

TABLE 10.8 DIRTY, COLORED, OR FOREIGN PARTICLES

COMPLAINT INVESTIGATION	POSSIBLE CAUSES FOR COMPLAINTS
1. *INFORMATION NEEDED*	1. *DISTRIBUTION SYSTEM*
What is location of premises?	Water treatment plant problems
Determine pressure zone of premises.	Breaks in mains
When was dirty water first detected?	Dead ends
What does the water look like?	Cross-connections
Does the water have a color?	New, recoated or repainted water mains, tanks, and reservoirs
Are both the hot and cold water dirty?	Fires
Is the water dirty at all faucets?	Flushing of fire hydrants
2. *FIELD INVESTIGATION*	Disturbance of consumer's service line
Check water at consumer's premises.	Changes in pressure zones
Eliminate dirty water by:	Pipe coatings and sand
(a) Flushing hydrants or blowoffs.	2. *PRIVATE PLUMBING SYSTEM*
(b) Flush house line if necessary.	Hot water systems
Take sample to laboratory if necessary.	Cross-connections
Report results of laboratory tests to customer.	House piping
	Plumbing repairs

TABLE 10.9 HARD WATER, SCALE, SPOTS ON GLASSWARE

COMPLAINT INVESTIGATION	POSSIBLE CAUSES OF COMPLAINTS
1. *INFORMATION NEEDED*	1. *DISTRIBUTION SYSTEM*
What is location of customer's premises?	Change of supply
Determine source of water supplied to customer.	Cross-connection
When was hard water or scale first detected?	Other causes
What was the means of measurement of water being harder than usual?	2. *PRIVATE PLUMBING SYSTEM*
2. *FIELD INVESTIGATION*	Cross-connection
Check water at customer's premises. Take samples to laboratory if necessary.	Other causes
Report results of laboratory tests to customer.	3. *GENERAL CONSUMER CONCERNS*
	Spots on bottles, glassware, boiler scale
	Soft water use, such as steam irons, batteries
	Soap rings in tubs, washing machines
	Types of soap vs. hardness
	Hardness determination
	Water softening

TABLE 10.10 SICKNESS OR SKIN IRRITATION

COMPLAINT INVESTIGATION	POSSIBLE CAUSES FOR COMPLAINT
1. *INFORMATION NEEDED*	1. *DISTRIBUTION SYSTEM*
What is location of customer's premises?	Change in supply
Determine source of water supplied to customer.	Cross-connection
When did the sickness first occur?	Other causes
Why is it thought that the sickness is due to water?	2. *PRIVATE PLUMBING SYSTEM*
Have all members of the family been affected?	Cross-connection
Have the affected members of the family been out of town recently?	Other causes
Has a doctor been consulted?	3. *GENERAL CONSUMER CONCERNS*
2. *FIELD INVESTIGATION*	Consumer's senses affected by illness, medication and/or diet
Check taste, odor, color, and turbidity of water at customer's premises.	
Check for cross-connections.	
Take sample to laboratory for bacteriological and partial chemical test.	
Report results of laboratory tests to consumer.	

TABLE 10.11 TASTES AND ODORS

COMPLAINT INVESTIGATION	POSSIBLE CAUSES FOR COMPLAINT
1. *INFORMATION NEEDED*	1. *DISTRIBUTION SYSTEM*
What is location of customer's premises?	Raw water
Determine source of water supplied to customer's premises.	Water treatment plant
When was taste or odor first detected?	Disinfection of new mains, tanks, or reservoirs
Is the taste or odor in both the hot and cold water?	Dead ends
Does consumer have a pressurized hose (gun-type nozzle)?	Cross-connections
2. *FIELD INVESTIGATION*	Water from a different source
Check water at customer's premises.	Miscellaneous causes
Suggest that consumer flush house lines.	2. *PRIVATE PLUMBING SYSTEM*
Flush hydrants or blow-offs if necessary.	Hot water tanks
Take sample to laboratory if necessary.	Cross-connections
Report results of laboratory tests to customer.	Old piping
	Exposed water lines
	Compounds added by customer to control corrosion or to protect boilers
	Kitchen sink odors
	Miscellaneous causes
	3. *GENERAL CONSUMER CONCERNS*
	Consumer's senses affected by tastes and odors

TABLE 10.12 WORMS OR BUGS

COMPLAINT INVESTIGATION	POSSIBLE CAUSES FOR COMPLAINT
1. *INFORMATION NEEDED*	1. *DISTRIBUTION SYSTEM*
What is location of customer's premises?	Distribution reservoirs
Determine source of water supplied to customer's premises.	Cross-connections
Where were the organisms first found?	Dead ends
How would you describe the organisms?	Main breaks, fires
	Water treatment plants
2. *FIELD INVESTIGATION*	Miscellaneous sources
Check water and sample of organisms at customer's premises.	2. *PRIVATE PLUMBING SYSTEM*
Flush house lines if necessary.	Cross-connections
Flush hydrants or blow-offs if necessary.	Organisms in bathtubs, bowls, wash basins
Report results of laboratory analysis to customer.	Organisms from miscellaneous sources

TABLE 10.13 AQUARIUM FISH PROBLEMS

COMPLAINT INVESTIGATION

1. *INFORMATION NEEDED*
   - What is location of customer's premises?
   - When did the fish first start to die?
   - When was water last added to the aquarium?
   - Were new fish added?
   - Have any new foods or plants been added?
   - Were any sprays used near the aquarium?
   - Is the aquarium new, or have new materials been used?
2. *FIELD INVESTIGATION*
   - Check water at customer's premises.
   - Take sample to laboratory if necessary.
   - Report results of laboratory tests to customer.

POSSIBLE CAUSES FOR COMPLAINT

1. *DISTRIBUTION SYSTEM*
   - pH of water
   - Chlorine residual
   - Copper content
   - Cross-connections
2. *PRIVATE PLUMBING SYSTEM*
   - pH of water
   - Chlorine residual
   - Copper content
   - Cross-connections
3. *GENERAL CONSUMER CONCERNS*
   - Change in temperature
   - Dissolved oxygen
   - Plant or insect sprays
   - Toxic materials used in construction of aquarium
   - Overloading of aquarium
   - Overfeeding or underfeeding of fish
   - Fish diseases
   - Chemicals used to prevent diseases
   - Miscellaneous causes

TABLE 10.14 GARDEN DAMAGE

COMPLAINT INVESTIGATION

1. *INFORMATION NEEDED*
   - What is location of customer's premises?
   - Source of supply?
   - When was plant damage first noticed?
   - Use of fertilizers or garden sprays?
   - Possible animal (dogs, cats) damage.
   - Possible damage by gophers, moles.
   - Plant sensitivity to sun, water, soil?
   - Frequency of watering?
2. *FIELD INVESTIGATION*
   - Test water at customer's premises for pH and chlorine residual.
   - Take sample to laboratory if necessary.
   - Report results of laboratory tests to customer.

POSSIBLE CAUSES FOR COMPLAINT

1. *DISTRIBUTION SYSTEM*
   - pH of water
   - Chlorine residual
   - Copper residual
   - Cross-connections
2. *PRIVATE PLUMBING SYSTEM*
   - pH of water
   - Chlorine residual
   - Cross-connections
3. *GENERAL CONSUMER CONCERNS*
   - Improper care of acid-loving plants
   - Over- or under-fertilizing
   - Over- or under-watering of plants
   - Plant diseases or insects
   - Damage by garden sprays or powders
   - Damage by dogs or cats
   - Damage by gophers, moles, deer, or other animals
   - Miscellaneous causes

plant. These sources are then tabulated, ranked by size of load, and prioritized to define the importance of each load source in the overall program. This basic evaluation will frequently point to areas where immediate savings can be achieved through simple changes in routine operations (for example, avoid backwashing a filter when another high load source is in operation).

Some utility suppliers have a "time-of-use" billing schedule, which provides the user with significant price breaks during "off-peak" demand periods. If possible, filter backwashing or other discretionary functions can be performed during off-peak periods to take advantage of these lower rates.

In its most sophisticated form, power management can be used to control all of the electrical loads in the water treatment plant. With the aid of a simple computer, each load can be monitored and controlled to provide the most cost-effective operating mode. In some instances, non-critical loads can be turned off (shed) for short time periods while higher priority loads are on-line. This can result in significant operational cost savings without compromising the safety and reliability of plant operations.

10.123 Power Cost Analysis

In order to properly assess the impact of power costs on your overall plant operating budget it is helpful to perform a monthly power cost analysis similar to the one shown in Figure 10.7, and discussed in the following paragraphs.

Basic to any power cost analysis is reading and recording electrical energy use on a monthly basis. This is accomplished by reading the plant utility meter or meters. Using the proper meter multiplier factor (1,000 in this example, column C), you can then determine the total amount of electrical energy used in KWH (kilowatt hours) during the month (shown in column E).

The KW (kilowatt) demand can also be read on the utility meter. This value represents the greatest single energy demand during the month (or prior months), and is generally billed as a separate cost component. Overall energy costs can generally be reduced by keeping demand to a minimum. Notice in column D that the demand normally varies with plant flow. This results from the higher demand for electrical equipment (pumps and motors) to produce the higher flow rates and operating pressures required during the warmer months. If you are careful, you can avoid creating high peak demands during the warmer months by shifting non-essential operations requiring electrical energy to off-peak hours. Some examples, such as backwashing filters during non-peak hours, have been discussed in the preceding sections.

Total power cost, as shown in column G, can be obtained from the monthly energy bill. Power costs can be calculated in convenient units such as $/MG as shown in column J. In this example, column J was obtained by dividing the total power cost shown in column G ($) by the total gallons of water pumped as shown in column I (MG). Monthly power costs are useful for checking the current budget allocation for energy and for preparing the following year's budget.

Keeping track of other treatment costs such as chemical costs (shown in columns K and L) and water cost (shown in column M) can also be useful to the operator as well as to supervisory personnel. If large variations in treatment costs appear in any given month, this analysis form will provide you with important clues to help explain or solve the problem.

The remarks column is provided for making comments on any unusual conditions which caused higher energy or chemical demands. These remarks will be helpful in budgeting for the next year, as well as reporting on the current year's performance (annual operating report).

10.13 REFERENCE BOOKS

As discussed in previous chapters, reference books and manuals are a valuable technical resource. A wide variety of reference material is available which describes how to perform routine laboratory tests, routine and complex process performance considerations, as well as other technical aspects of water treatment plant operations.

The following is a suggested list of reference books which will help you understand the more complex aspects of water treatment. This list is not intended to be a critical or complete reference source on the topic, as there are a number of other good reference books available.

SUGGESTED REFERENCES

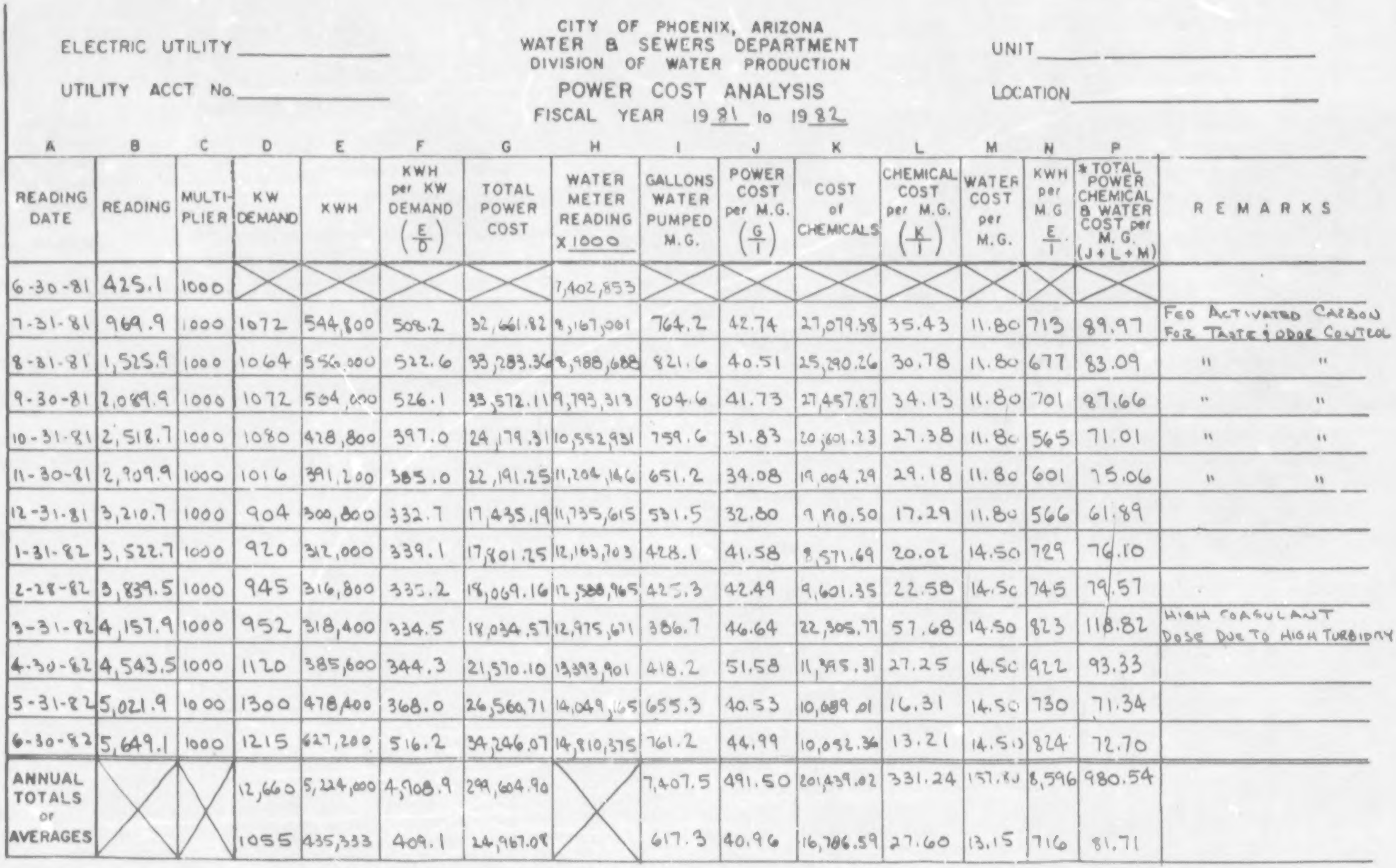
1. *CHEMISTRY FOR ENVIRONMENTAL ENGINEERS*, C. N. Sawyer and P. L. McCarty, Third Edition, 1978, McGraw-Hill Book Company, 1221 Avenue of the Americas, New York, New York 10020. Price, $24.50
2. *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER*, published jointly by the American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 15th Edition, 1980. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Catalog No. 10019 JZ. Price to members, $40.00; nonmembers, $50.00.
3. *WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES*, American Water Works Association, Third Edition, McGraw-Hill, 1971. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10008. Price to members, $34.10; nonmembers, $42.60.
4. *WATER TREATMENT PLANT DESIGN*, prepared jointly by the American Water Works Association, and Conference of State Sanitary Engineers, AWWA, 1969. Available from Data Processing Department, AWWA, 6666 W. Quincy Ave., Denver, Colorado 80235. Order No. 10006. Price to members, $14.40; nonmembers, $18.00.

10.14 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.138, "Plant Operation." Check all of the arithmetic in this section using an electronic pocket calculator. You should be able to get the same answers.

10.15 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 17, "Protection of Treated Water," Chapter 18, "Records and Reports," and Chapter 19, "Treatment Plant Maintenance and Accident Prevention."
2. *TEXAS MANUAL*, Chapter 16, "Storage of Potable Water," Chapter 18, "Effective Public Relations in Water Works Operations," and Chapter 23, "Emergency Operations."



CITY OF PHOENIX, ARIZONA
WATER & SEWERS DEPARTMENT
DIVISION OF WATER PRODUCTION
POWER COST ANALYSIS
FISCAL YEAR 19 81 to 19 82

ELECTRIC UTILITY ____________
UTILITY ACCT No. ____________
UNIT ____________
LOCATION ____________

A	B	C	D	E	F	G	H	I	J	K	L	M	N	P	
READING DATE	READING	MULTIPLIER	KW DEMAND	KWH	KWH per KW DEMAND $\left(\frac{E}{D}\right)$	TOTAL POWER COST	WATER METER READING X 1000	GALLONS WATER PUMPED M.G.	POWER COST per M.G. $\left(\frac{G}{I}\right)$	COST of CHEMICALS	CHEMICAL COST per M.G. $\left(\frac{K}{I}\right)$	WATER COST per M.G.	KWH per M.G. $\frac{E}{I}$	*TOTAL POWER CHEMICAL & WATER COST per M.G. (J+L+M)	REMARKS
6-30-81	425.1	1000					7,402,853								
7-31-81	969.9	1000	1072	544,800	508.2	32,661.82	8,167,001	764.2	42.74	27,079.38	35.43	11.80	713	89.97	FED ACTIVATED CARBON FOR TASTE & ODOR CONTROL
8-31-81	1,525.9	1000	1064	556,000	522.6	33,283.36	8,988,688	821.6	40.51	25,290.26	30.78	11.80	677	83.09	" "
9-30-81	2,089.9	1000	1072	564,000	526.1	33,572.11	9,793,313	804.6	41.73	27,457.87	34.13	11.80	701	87.66	" "
10-31-81	2,518.7	1000	1080	428,800	397.0	24,179.31	10,552,931	759.6	31.83	20,601.23	27.38	11.80	565	71.01	" "
11-30-81	2,909.9	1000	1016	391,200	385.0	22,191.25	11,204,146	651.2	34.08	19,004.29	29.18	11.80	601	75.06	" "
12-31-81	3,210.7	1000	904	300,800	332.7	17,435.19	11,735,615	531.5	32.80	9,110.50	17.29	11.80	566	61.89	
1-31-82	3,522.7	1000	920	312,000	339.1	17,801.25	12,163,703	428.1	41.58	8,571.69	20.02	14.50	729	76.10	
2-28-82	3,839.5	1000	945	316,800	335.2	18,069.16	12,588,965	425.3	42.49	9,601.35	22.58	14.50	745	79.57	
3-31-82	4,157.9	1000	952	318,400	334.5	18,034.57	12,975,671	386.7	46.64	22,305.77	57.68	14.50	823	118.82	HIGH COAGULANT DOSE DUE TO HIGH TURBIDITY
4-30-82	4,543.5	1000	1120	385,600	344.3	21,570.10	13,393,901	418.2	51.58	11,395.31	27.25	14.50	922	93.33	
5-31-82	5,021.9	1000	1300	478,400	368.0	26,560.71	14,049,165	655.3	40.53	10,689.01	16.31	14.50	730	71.34	
6-30-82	5,649.1	1000	1215	627,200	516.2	34,246.07	14,810,375	761.2	44.99	10,052.36	13.21	14.50	824	72.70	
ANNUAL TOTALS or AVERAGES			12,660 1055	5,224,000 435,333	4,908.9 409.1	299,604.90 24,967.08		7,407.5 617.3	491.50 40.96	201,439.02 16,786.59	331.24 27.60	157.80 13.15	8,596 716	980.54 81.71	

* For comparison purposes only. Labor and fixed charges not included.

Fig. 10.7 Power cost analysis

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10.16 ACKNOWLEDGMENT

Many of the concepts and procedures discussed in this chapter are based on material obtained from the sources listed below.

1. Stone, B. G. Notes from "Design of Water Treatment Systems," CE-610, Loyola Marymount University, Los Angeles, CA, 1977.
2. *WATER QUALITY AND TREATMENT: A HANDBOOK OF PUBLIC WATER SUPPLIES*, American Water Works Association, Third Edition, McGraw-Hill, 1971.
3. *WATER TREATMENT PLANT DESIGN*, prepared jointly by the American Water Works Association, and Conference of State Sanitary Engineers, AWWA, 1969.
4. *OPERATION AND MAINTENANCE MANUAL FOR STOCKTON EAST WATER TREATMENT PLANT*, James M. Montgomery, Consulting Engineers, Inc., Walnut Creek, CA, 1979.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 452.

10.12A List the major sources of energy consumption in the operation of a water treatment plant.

10.12B How can the consumption of electrical energy at a water treatment plant be reduced?

End of Lesson 2 of 2 Lessons on PLANT OPERATION

DISCUSSION AND REVIEW QUESTIONS

Chapter 10. PLANT OPERATION

(Lesson 2 of 2 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 453. The question numbering continues from Lesson 1.

9. What records should be maintained as part of a good records management system?
10. What is a work order system?
11. Prepare a list of daily operating procedures for your plant.
12. How would you determine the raw water pumping rate to a water treatment plant?
13. If a water treatment plant must be shut down for emergency repairs, how would you try to prepare for this event?
14. What would you do if the entire chemical feed system (coagulants and polymers) for your plant failed?
15. Outline a procedure for handling complaints.
16. How can energy requirements for lighting be reduced in a water treatment plant?

SUGGESTED ANSWERS

Chapter 10. PLANT OPERATION

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 419.

10.0A. The first priority for operating a water treatment plant is the production of a safe drinking water, one that is free of harmful bacteria and toxic materials.

10.0B Water that appeals to consumers must be clear (free of turbidity), colorless, and free of objectionable tastes and odors. Consumers also show a preference for water supplies that do not stain plumbing fixtures and clothes, do not corrode plumbing fixtures and piping, and do not leave scale deposits or spot glassware.

Answers to questions on page 421.

10.1A Grab samples are used when measuring water quality indicators that can change after collection, such as coliforms, pH and temperature.

10.1B Turbidity must be removed in order for disinfection to be effective in killing disease-causing organisms.

Answers to questions on page 423.

10.2A Your first task upon arrival at a water treatment plant should be to review what has happened during the last shift or since you left the plant.

10.2B Operators control finished water quality mainly by the proper application of chemicals.

10.2C Tasks that an operator should do during the day include: (1) backwash or check filters, (2) monitor system pressures, (3) check storage in clear well, (4) monitor and adjust pumping rates, and (5) perform quality control checks.

10.2D Tasks that an operator should do at the end of the day are the same as those listed under 10.2C plus anticipate raw water and finished water pumping rates, check chemical dosage facilities and secure plant for the night.

Answers to questions on page 427.

10.3A Data can be transmitted over distances greater than 1500 feet by telephone tone, microwave, or radio transmission.

10.3B The air supply for pneumatic data transmission devices must be dried to prevent condensation in equipment signal lines, and filtered to remove particle contaminants.

10.3C Water, water and oil, and glycerol are frequently used transmission fluids in hydraulic systems.

10.3D Functions commonly performed by electronic signals include (1) indication, (2) recording, (3) data logging, (4) alarm, and (5) control.

Answers to questions on page 427.

10.3E A hybrid instrumentation system is a combination of many different types of instrumentation systems.

10.3F Relay logic is a method of switching electrical power on and off in accordance with a predetermined sequence (logic) by means of relay switches, contacts, timers, and manual switches.

Answers to questions on page 429.

10.4A Factors which influence the amount of water which must be treated each day include current storage levels in clear wells and distribution system service storage reservoirs. Other important factors include expected consumer demand based on historical and current trends as well as weather conditions.

10.4B During periods of peak demands for water, clear wells are drawn down to provide water to meet the demands.

10.4C Filters are usually operated at a constant rate. When large flow changes occur, either more filters are put in service or some filters are taken out of service.

Answers to questions on page 432.

10.5A A pilot plant is a "small scale" water treatment plant built at or near the source of supply. Pilot tests provide the designer, as well as the treatment plant operator, with valuable information on the "treatability" of a given source of supply over a broad range of water quality conditions.

10.5B Water treatment chemicals can be stored in a number of ways including (1) solid (dry) form (bags, cartons, drums), (2) liquid form (drums, tanks, cylinders), or (3) gaseous form (cylinders).

10.5C Protective clothing should be worn when working with chemicals. Goggles and faceshields will protect your eyes and face. Other exposed portions of the body should be protected by wearing rubber or neoprene gloves, aprons or other protective clothing. Use respirators when working with chemical dust, and always use dust collectors when such equipment is provided.

10.5D Wherever chlorine liquid or gas are stored or used, the following safety equipment should be provided:

1. Shower and eyewash facilities,
2. Emergency breather apparatus (air pack),
3. Chlorine gas detector,
4. Floor-level vents, and
5. Fans that maintain a positive air pressure.

Answers to questions on page 433.

10.6A The two major categories of operating records are (1) physical records and (2) performance records.

10.6B Performance records describe the operation of the water treatment plant.

10.6C Records that may have historical value to the operator include source water quality changes and resultant process changes.

10.6D Each operator should use a pocket notebook to record unique or unusual events.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 439.

10.7A The major elements of a good preventive maintenance (P/M) program include: (1) planning and scheduling, (2) records management, (3) spare parts management, (4) cost and budget control, (5) work order system, (6) emergency repair procedures, and (7) operator training program. Also the maintenance program must be capable of dealing effectively with emergency conditions.

10.7B A comprehensive records management system provides the basis for daily task assignments, provides a permanent record of work performed, and becomes a historical reference source for reviewing equipment performance.

10.7C Items that should be included in a cost and budget control program include accurate records of labor and equipment expenditures as well as costs of equipment operations, repair and replacement.

Answers to questions on page 440.

10.8A Potential hazards an operator could be exposed to during the routine operation of a water treatment plant include: (1) electrical equipment (shocks), (2) rotating mechanical equipment, (3) water treatment chemicals, (4) laboratory reagents (chemicals), (5) open-surface, water-filled structures (drowning), (6) underground structures (toxic and explosive gases, lack of oxygen), and (7) pumping stations (high noise levels).

10.8B An operator should routinely inspect plant facilities at least once per shift for any evidence of unauthorized persons or unusual events.

Answers to questions on page 442.

10.9A Treatment process failures are usually caused by (1) changes in raw water quality, (2) operator error, or (3) equipment failure.

10.9B The best safeguard against premature process equipment failures is a good preventive maintenance program.

10.9C If the prechlorination facility failed, (1) shut down immediately and repair, or (2) rely strictly on postchlorination.

Answers to questions on page 443.

10.9D Emergency power is usually provided at water treatment plants as a backup electrical power source for use in the event of commercial power failure.

10.9E If a fire occurs at your water treatment plant, immediately notify the local fire department, and then determine the source and severity of the fire. Depending on the type of fire, use the appropriate fire safety equipment available at the plant in an attempt to extinguish the fire.

10.9F After a major flood the operator should try to get the plant back on line and functioning properly. Items that should be checked include: (1) inspecting all facilities for accessibility, (2) checking condition and function of all process equipment, (3) checking structures and chemical storage tanks for structural or other damage, (4) checking the plant piping system for leaks and other visual signs of damage, (5) preparing a preliminary damage report, and (6) reporting conditions to plant supervisory personnel.

Answers to questions on page 443.

10.10A NPDES stands for **N**ational **P**ollutant **D**ischarge **E**limination **S**ystem.

10.10B Most suspended solids are removed by the sedimentation and filtration processes at water treatment plants.

Answers to questions on page 444.

10.11A Common types of consumer complaints include:

1. Air and/or milky water,
2. Dirty, colored, or foreign particles,
3. Hard water, scale, spots on glassware,
4. Sickness or skin irritation,
5. Tastes and odors,
6. Worms or bugs,
7. Aquarium fish problems, and
8. Garden damage.

10.11B Air in water can be eliminated by (1) flushing house lines if necessary, or (2) flushing hydrants or blowoffs if necessary.

10.11C If a consumer complained regarding water causing a sickness,

1. Check taste, odor, color and turbidity of water at consumer's premises,
2. Look for cross-connections,
3. Take sample to laboratory for bacteriological and partial chemical test, and
4. Report results of laboratory test to consumer.

Answers to questions on page 450.

10.12A In the operation of a water treatment plant, energy may be consumed for lighting, heating and air-conditioning, and powering numerous electrical motors throughout the plant.

10.12B Consumption of electrical energy may be reduced by replacing old electric motors with high efficiency motors as the old ones burn out. Consideration should also be given to installing capacitors at the treatment plant to correct a low power factor.

OBJECTIVE TEST

Chapter 10. PLANT OPERATION

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE-FALSE

1. Water treatment plant operators must realize that water can degrade in the distribution system.
   1. True
   2. False
2. Most safety instrumentation and control devices are of the mechanical type because of their reliability.
   1. True
   2. False
3. Strip chart recorders are being installed to replace computers.
   1. True
   2. False
4. Clear wells are filled during high system demands for water.
   1. True
   2. False
5. The use of chemicals is the single most important tool available to operators for adjusting and controlling process performance.
   1. True
   2. False
6. Operators should consider the weather forecast when selecting a raw water pumping rate.
   1. True
   2. False
7. Combined chlorine residuals are more effective than free chlorine residuals in disinfecting water.
   1. True
   2. False
8. Spare parts should be stocked on the basis of the importance of the part to plant operation.
   1. True
   2. False
9. Caustic soda is an inert chemical.
   1. True
   2. False
10. Planning and scheduling are the backbone of good maintenance programs.
    1. True
    2. False
11. Always report any accident or personal injury to your immediate supervisor.
    1. True
    2. False
12. Operators should try to adjust raw water pumping rates during the day to match system demands.
    1. True
    2. False
13. Accidental chemical spills are usually detected by monitoring equipment in the plant's intake.
    1. True
    2. False
14. Alum is a source of sludge solids in water treatment plants.
    1. True
    2. False
15. Complaints are often the way in which operators learn that service being given may be unsatisfactory.
    1. True
    2. False

MULTIPLE CHOICE

16. Inorganic chemicals listed in the Primary Drinking Water Standards include
    1. Arsenic.
    2. Lindane.
    3. Odor.
    4. Turbidity.
    5. Zinc.
17. In a conventional surface water treatment plant, which *ONE* of the following water quality indicators do operators have the greatest control over?
    1. Alkalinity
    2. Hardness
    3. Iron and manganese
    4. Temperature
    5. Turbidity
18. Instruments and controls in water treatment plants are used to
    1. Alarm.
    2. Control.
    3. Indicate.
    4. Measure.
    5. Record.
19. Water temperature is commonly monitored at the
    1. Clear well.
    2. Filters.
    3. Finished water.
    4. Raw water.
    5. Wash water.

20. Water levels may be sensed by
    1. Bubblers.
    2. Floats.
    3. Rotameters.
    4. Sonic means.
    5. Venturis.

21. Demands for water may vary depending on
    1. Day of week.
    2. Prevailing weather conditions.
    3. Season of year.
    4. Time of day.
    5. Water appearance.

22. Selection of a chemical to treat water depends on
    1. Availability of chemical.
    2. Economics.
    3. Source water quality.
    4. Type of community.
    5. Type of treatment.

23. Which of the following chemicals is (are) commonly used to treat tastes and odors?
    1. Alcohol
    2. Hydrochloric acid
    3. Lime
    4. Potassium permanganate
    5. Sodium hydroxide

24. The selection of a chemical feed system for a given application depends on the
    1. Amount to be fed.
    2. Chemical form (dry or liquid).
    3. Location of application.
    4. Type of chemical compound.
    5. Type of distribution system.

25. Water treatment plants should have a ________ day supply of chlorine at all times.
    1. 1-2
    2. 2-5
    3. 5-10
    4. 10-15
    5. 15-30

26. Important considerations when developing a good maintenance plan include
    1. Location of water source.
    2. Operator skills.
    3. Parts availability.
    4. Special tools
    5. System pressures.

27. Electrical shock may be avoided by
    1. Grounding all electrical tools.
    2. Locking out electrical circuits when working on equipment.
    3. Not grounding yourself in water.
    4. Not using metal ladders around electrical equipment.
    5. Using protective gloves.

28. Which of the following tasks should an operator do upon arrival at a water treatment plant at the start of a day or shift?
    1. Check clear well storage
    2. Check raw and finished water quality for any changes
    3. Review system pressures
    4. Start preventive maintenance program
    5. Walk through plant

29. What should an operator be doing while walking through a water treatment plant?
    1. Feeling
    2. Listening
    3. Looking
    4. Smelling
    5. Tasting finished water at end of walk.

30. Raw water quality can change due to
    1. Changes in system pressures.
    2. Chemical spills.
    3. Increase in system demands.
    4. Storm water runoff.
    5. Turbidity in finished water.

31. Power for emergency-generator sets usually comes from
    1. Diesel fuel.
    2. Liquid petroleum gas.
    3. Natural gas.
    4. Solar power.
    5. Wind.

32. The major source of sludge solids to be disposed of as a result of water treatment comes from ________ in the source water.
    1. Alkalinity
    2. BOD
    3. Carbon dioxide
    4. Iron and manganese
    5. Suspended solids

33. Critical pieces of equipment in a water treatment plant which must have standby or backup equipment include
    1. Chlorinators.
    2. Pumps to distribution system.
    3. Raw water pumps.
    4. Sludge pumps.
    5. Sludge scrapers.

34. Common types of consumer complaints include
    1. Aquarium fish problems.
    2. Excess alkalinity.
    3. Soft water.
    4. Spots on glassware.
    5. Tastes and odors.

35. Estimate the average chlorine use in pounds of chlorine per day from the information given below:

Day	M	T	W	TH	F	S	S
Chlorine, lbs/day	73	62	65	58	69	57	49

    1. 49 lbs/day
    2. 60 lbs/day
    3. 62 lbs/day
    4. 65 lbs/day
    5. 73 lbs/day

End of Objective Test

CHAPTER 11

LABORATORY PROCEDURES

by

Jim Sequeira

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OBJECTIVES

Chapter 11. LABORATORY PROCEDURES

Following completion of Chapter 11, you should be able to:

1. Work safely in a laboratory,
2. Operate laboratory equipment,
3. Collect representative samples and also preserve and transport the samples,
4. Prepare samples for analysis,
5. Describe the limitations of lab tests,
6. Recognize precautions to be taken for lab tests,
7. Record laboratory test results, and
8. Perform the following field or laboratory tests — alkalinity, residual chlorine, coliform, hardness, jar test, pH, temperature and turbidity.

GLOSSARY

Chapter 11 LABORATORY PROCEDURES

ACIDIC (uh-SID-ick)	ACIDIC

The condition of water or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

ALIQUOT (Al-li-kowt)	ALIQUOT

Portion of a sample.

ALKALI (AL-ka-lie)	ALKALI

Various soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical water treatment processes.

ALKALINE (AL-ka-LINE)	ALKALINE

The condition of water or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

AMBIENT TEMPERATURE (AM-bee-ent)	AMBIENT TEMPERATURE

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

AMPEROMETRIC (am-PURR-o-MET-rick)	AMPEROMETRIC

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION	AMPEROMETRIC TITRATION

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. See TITRATE.

ASEPTIC (A-SEP-tick)	ASEPTIC

Free from the living germs of disease, fermentation or putrefaction. Sterile.

BACTERIA (back-TEER-e-uh)	BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BLANK	BLANK

A bottle containing only dilution water or distilled water; the sample being tested is not added. Tests are frequently run on a SAMPLE or a BLANK and the differences compared.

BUFFER	BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.

BUFFER CAPACITY	BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT	CALCIUM CARBONATE ($CaCO_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalence to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CARCINOGEN (car-SIN-o-jen)	CARCINOGEN

Any substance which tends to produce cancer in an organism.

CHLORORGANIC (klor-or-GAN-nick) CHLORORGANIC

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

COMPOSITE (come-PAH-zit) (PROPORTIONAL) SAMPLES COMPOSITE (PROPORTIONAL) SAMPLES

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

COMPOUND COMPOUND

A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride-NaCl) is a compound.

DESICCATOR (DESS-uh-KAY-tor) DESSICATOR

A closed container into which heated weighing or drying dishes are placed to cool in a dry environment. The dishes may be empty or they may contain a sample. Desiccators contain a substance, such as anhydrous calcium chloride, which absorbs moisture and keeps the relative humidity near zero so that the dish or sample will not gain weight from absorbed moisture.

DISINFECTION (dis-in-FECT-shun) DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DPD DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N, N-diethyl-p-phenylene-diamine.

ELEMENT ELEMENT

A substance which cannot be separated into its constituent parts and still retain its chemical identity. For example, sodium (Na) is an element.

END POINT END POINT

Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs. This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

FACULTATIVE (FACK-ul-TAY-tive) FACULTATIVE

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food material such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.

FLAME POLISHED FLAME POLISHED

Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.

GRAB SAMPLE GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

GRAVIMETRIC GRAVIMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample by *WEIGHING* a precipitate or residue of the sample.

INDICATOR (CHEMICAL) INDICATOR (CHEMICAL)

A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

INORGANIC

INORGANIC

Material, such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

M OR MOLAR

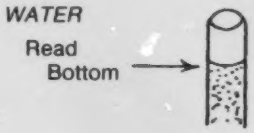
M OR MOLAR

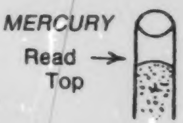
A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A one *M* solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MENISCUS (meh-NIS-cuss)

MINISCUS

The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.





MILLIGRAMS PER LITER, mg/*L*

MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes one mg/*L* of a substance in fresh water is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/*L*), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).

MOLE

MOLE

The molecular weight of a substance, usually expressed in grams.

MOLECULAR WEIGHT

MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

MOLECULE (MOLL-uh-kule)

MOLECULE

The smallest division of a compound that still retains or exhibits all the properties of the substance.

MPN (pronounce as separate letters)

MPN

MPN is the **M**ost **P**robable **N**umber of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 m*L* of sample water.

N OR NORMAL

N OR NORMAL

A normal solution contains one gram equivalent weight of reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1 *N* solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

NEPHELOMETRIC (NEFF-el-o-MET-rick)

NEPHELOMETRIC

A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

ORGANIC

ORGANIC

Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

ORGANISM

ORGANISM

Any form of animal or plant life. Also see BACTERIA.

OSHA OSHA

The Williams-Steiger **O**ccupational **S**afety and **H**ealth **A**ct of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

PPM or parts per million PPM

Parts per million parts, a measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/*L*) which is the preferred term.

PATHOGENIC ORGANISMS (path-o-JEN-nick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of bacteria which do *NOT* cause disease. These organisms are called non-pathogenic.

PATHOGENS (path-o-JENS) PATHOGENS

Pathogenic or disease-causing organisms.

PERCENT SATURATION PERCENT SATURATION

The amount of a substance that is dissolved in solution compared with the amount that could be dissolved in the solution, expressed as a percent.

$$\text{Percent Saturation, \%} = \frac{\text{Amount of Substance That is Dissolved}}{\text{Amount That Could Be Dissolved in Solution}} \times 100\%$$

pH (pronounce as separate letters) pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \text{Log}\ \frac{1}{(\text{H}^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered safe for domestic consumption.

PRECIPITATE (pre-SIP uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or measure, detect, or examine other substances.

REDUCTION (re-DUCK-shun) REDUCTION

Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

SOLUTION SOLUTION

A liquid mixture of dissolved substances. In a solution it is impossible to see all the separate parts.

STANDARD SOLUTION STANDARD SOLUTION

A solution in which the exact concentration of a chemical or compound is known.

STANDARDIZE STANDARDIZE

(1) To compare with a standard. In wet chemistry, to find out the exact strength of a solution by comparing with a standard of known strength.
(2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

STERILIZATION (STARE-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

SURFACTANT (sir-FAC-tent) SURFACTANT

Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge or floc. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TURBIDITY UNITS (TU) (ter-BID-it-tee) TURBIDITY UNITS

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity units which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

VOLATILE ACIDS VOLATILE ACIDS

Acids produced during digestion. Fatty acids which are soluble in water and can be steam-distilled at atmospheric pressure. Also called "organic acids." Volatile acids are commonly reported as equivalent to acetic acid.

VOLATILE LIQUIDS VOLATILE LIQUIDS

Liquids which easily vaporize or evaporate at room temperatures.

VOLATILE SOLIDS VOLATILE SOLIDS

Those solids in water or other liquids that are lost on ignition of the dry solids at 550°C.

VOLUMETRIC VOLUMETRIC

A measurement based on the volume of some factor. Volumetric titration is a means of measuring unknown concentrations of water quality indicators in a sample by determining the volume of titrant or liquid reagent needed to complete particular reactions.

Chapter 11. LABORATORY PROCEDURES

(Lesson 1 of 5 Lessons)

11.0 BASIC WATER LABORATORY PROCEDURES

11.00 Importance of Laboratory Procedures

Water treatment processes cannot be controlled effectively unless the operator has some means to check and evaluate the quality of water being treated and produced. Laboratory quality control tests provide the necessary information to monitor the treatment processes and insure a safe and good-tasting drinking water for all who use it. By relating laboratory results to treatment operations, the water treatment or supply system operator can first select the most effective operational procedures, then determine the efficiency of the treatment processes, and identify potential problems before they affect finished water quality. For these reasons, a clear understanding of laboratory procedures is a must for every waterworks operator.

NOTICE

THE COLLECTION OF A BAD SAMPLE OR A BAD LABORATORY RESULT IS ABOUT AS USEFUL AS NO RESULTS. TO PREVENT BAD RESULTS REQUIRES (1) CONSTANT MAINTENANCE AND CALIBRATION OF LABORATORY EQUIPMENT AND (2) USE OF CORRECT LAB PROCEDURES. ALSO RESULTS OF LAB TESTS ARE OF NO VALUE TO ANYONE UNLESS THEY ARE USED.

11.01 Metric System

The metric system is used in the laboratory to express units of length, volume, weight (mass), concentration and temperature. The metric system is based on the decimal system. All units of length, volume, and weight use factors of 10 to express larger or smaller quantities of these units. Below is a summary of metric and English unit names and their abbreviations.

Type of Measurement	English System	Metric Name	Metric Abbreviation
Length	inch foot yard	meter	m
Temperature	Fahrenheit	Celsius	°C
Volume	quart gallon	liter	*L*
Weight	ounce pound	gram	g
Concentration	lbs/gal strength, %	milligrams per liter	mg/*L*

Many times in the water laboratory we use smaller amounts than a meter, a liter, or a gram. To express these smaller amounts, prefixes are added to the names of the base metric unit. There are many prefixes in use; however, we commonly use two or three prefixes more than any others in the laboratory.

Prefix	Abbreviation	Meaning
centi-	c	1/100 of; or 0.01 times
milli-	m	1/1000 of; or 0.001 times
micro-	μ	1/1,000,000 of; or 0.000001 times

One centimeter (cm) is 1/100 (one hundredth) of a meter, one milliliter (m*L*) is 1/1000 (one thousandth) of a liter, and likewise, one microgram (μg) is 1/1,000,000 (one millionth) of a gram.

EXAMPLES

(1) Convert 3 grams into milligrams.

1 milligram = 1 mg = 1/1000 grams

therefore, 1 gram = 1,000 milligrams

(3 grams) (1000 mg/gram) = 3000 mg

(2) Convert 750 milliliters (m*L*) to liters.

1 m*L* = 1/1000 liter

therefore, 1 liter = 1000 m*L*

(750 m*L*) (1 liter/1000 m*L*) = 0.750 liters

(3) Convert 50 micrograms (μg) to grams.

1 μg = 1/1,000,000 gram

therefore, 1 gram = 1,000,000 μg

50 μg × 1 gram/1,000,000 μg = 0.00005 grams

Larger amounts than a meter, liter, or gram can be expressed using such prefixes as kilo- meaning 1000. A kilogram is 1000 grams.

The Celsius (or centigrade) temperature scale is used in the water laboratory rather than the more familiar Fahrenheit scale.

	Fahrenheit (°F)	Celsius (°C)
Freezing point of water	32	0
Boiling point of water	212	100

To convert Fahrenheit to Celsius you can use the following formula:

Temperature, °C = 5/9 (°F-32)

EXAMPLE Convert 68°F to °C

$$\begin{aligned}\text{Temperature, °C} &= 5/9\ (\text{°F}-32\text{°F})\\ &= 5/9\ (68\text{°F}-32\text{°F})\\ &= 5/9\ (36)\\ &= 20\text{°C}\end{aligned}$$

To convert Celsius to Fahrenheit, the following formula can be used:

$$\text{Temperature, °F} = 9/5\ (\text{°C}) + 32\text{°F}$$

EXAMPLE Convert 35°C to °F

$$\begin{aligned}\text{Temperature, °F} &= 9/5\ (\text{°C}) + 32\text{°F}\\ &= 9/5\ (35\text{°C}) + 32\text{°F}\\ &= 63 + 32\\ &= 95\text{°F}\end{aligned}$$

11.02 Chemical Names and Formulas

In the laboratory, chemical symbols are used as "shorthand" for the names of the elements. The names and symbols for some of these elements are listed below.

Chemical Name	Symbol
Calcium	Ca
Carbon	C
Chlorine	Cl
Copper	Cu
Fluorine	F
Hydrogen	H
Iron	Fe
Magnesium	Mg
Manganese	Mn
Nitrogen	N
Oxygen	O
Sodium	Na
Sulfur	S

Ca
H
Cl
F
Cu
C
O
Fe
Na

A compound is a pure substance composed of two or more different elements and whose composition (proportion of elements) is constant. Generally, all chemical compounds can be divided into two main groups, organic and inorganic. Organic compounds are those which contain the element carbon (C). There are, however, a few simple substances containing carbon which are considered to belong to the realm of inorganic chemistry. These include carbon dioxide (CO_2), carbon monoxide (CO), bicarbonate (HCO_3^-) and carbonate (CO_3^{2-}) as in calcium carbonate ($CaCO_3$).

Many different compounds can be made from the same two or three elements. Therefore, you must carefully read the formula and name to prevent errors and accidents. A chemical formula is a "shorthand" or abbreviated way to write the name of a chemical compound. For example, the name sodium chloride (common table salt) can be written "NaCl." Table 11.1 lists commonly used chemical compounds found in the water laboratory.

TABLE 11.1 NAMES AND FORMULAS OF CHEMICALS COMMONLY USED IN WATER ANALYSES

Chemical Name	Chemical Formula
Acetic Acid	CH_3COOH
Aluminum Sulfate (alum)	$Al_2(SO_4)_3 \cdot 14.3\ H_2O$[a]
Ammonium Hydroxide	NH_4OH
Calcium Carbonate	$CaCO_3$
Chloroform	$CHCl_3$
Copper Sulfate	$CuSO_4$
Ferric Chloride	$FeCl_3$
Nitric Acid	HNO_3
Phenylarsine Oxide	C_6H_5AsO
Potassium Iodide	KI
Sodium Bicarbonate	$NaHCO_3$
Sodium Hydroxide	NaOH
Sulfuric Acid	H_2SO_4

[a] 14.3 H_2O. Alum in the dry form based on 17% Al_2O_3.

Poor results and safety hazards are often caused by using a chemical from the shelf that is *NOT* exactly the same chemical called for in a particular procedure. The mistake usually occurs when the chemicals have similar names or formulas. This problem can be eliminated if you use *BOTH* the chemical name and formula as a double check. The spellings of many chemical names are quite similar. These slight differences are critical because the chemicals do not behave alike. For example, the chemicals potassium nitr*A*te (KNO_3) and potassium nitr*I*te (KNO_2) are just as different in meaning chemically as the words f*A*t and f*I*t are to your doctor.

11.03 Helpful References

1. *METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES*, EPA 600/4-79-020, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.
2. *SIMPLIFIED PROCEDURES FOR WATER EXAMINATION-M12*, 1978, Order 30012. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members $16.30; non-members $20.40.
3. *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER*, 15th Edition, 1980, Order No. 10019. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price to members $40.00; nonmembers $50.00.
4. *HANDBOOK FOR ANALYTICAL QUALITY CONTROL IN WATER AND WASTEWATER LABORATORIES*, EPA 600/4-79-019, Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 26 W. St. Clair Street, Cincinnati, Ohio 45268.

5. *MICROBIOLOGICAL METHODS FOR MONITORING THE ENVIRONMENT*, U.S. Environmental Protection Agency, December 1978. Available through the National Technical Information Service, Springfield, Virginia 22161. Order No. EPA-600/8-78-017, Price $26.00.

6. *INTRODUCTION TO WATER QUALITY ANALYSIS*, Volume 4, Order. No. 1931. Available from Data Processing Department, American Water Works Association, 6666 W. Quincy Avenue, Denver, Colorado 80235. Price $11.00.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 522.

11.0A Why are laboratory control tests important?

11.0B What does the prefix milli- mean?

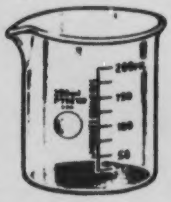
11.0C What's the proper name of the chemical compound, $CaCO_3$?

11.1 LABORATORY EQUIPMENT AND TECHNIQUES

11.10 Water Laboratory Equipment

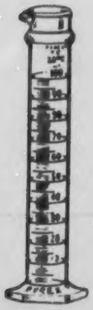
The items of equipment in a water laboratory are the operator's "tools-of-the-trade." In any laboratory there are certain basic pieces of equipment that are used routinely to perform tests such as those used in water analysis. The following is a brief description of several of the more common items of glassware and pieces of equipment used in the analysis of water.

BEAKERS. Beakers are the most common pieces of laboratory equipment. They come in sizes from 1 m*L* to 4000 m*L*. They are used mainly for mixing chemicals and to measure approximate volumes.



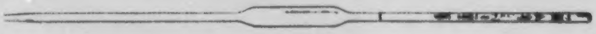
Beaker

GRADUATED CYLINDERS. Graduated cylinders also are basic to any laboratory and come in sizes from 5 m*L* to 4000 m*L*. They are used to measure volumes more accurately than beakers.

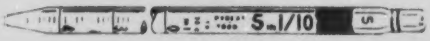


Cylinder, Graduated

PIPETS. Pipets are used to deliver accurate volumes and range in size from 0.1 m*L* to 100 m*L*.

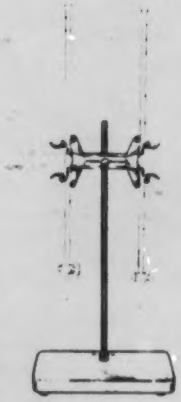


Pipet
(PIE-pet)
Volumetric

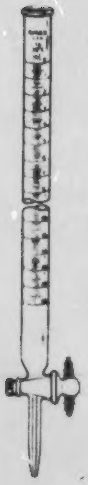


Pipet, Serological

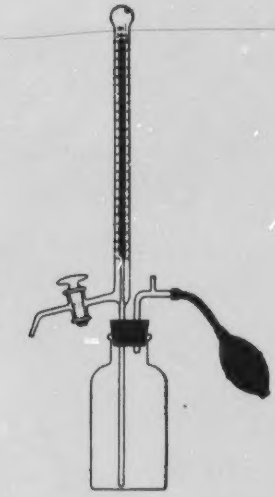
BURETS. Burets are also used to deliver accurate volumes. They are especially useful in a procedure called "titration." Burets come in sizes from 10 to 1000 m*L*.



Support, Buret & Buret Clamp

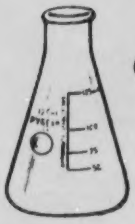


Buret
(bur-RET)

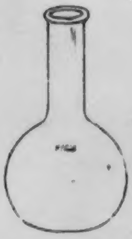


Automatic
Buret

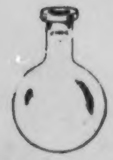
FLASKS. Flasks are used for containing and mixing chemicals. There are many different sizes and shapes.



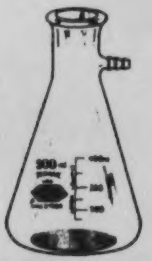
Flask,
Erlenmeyer
(ER-len-MY-er)
Wide Mouth



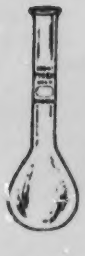
Flask,
Boiling
Flat Bottom



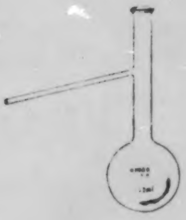
Flask,
Boiling
Round Bottom
Short Neck



Flask,
Filtering

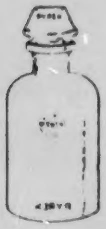


Kjeldahl Flask
(Kell-doll)

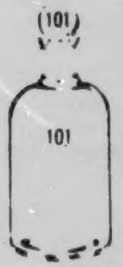


Flask,
Distilling

BOTTLES. Bottles are used to store chemicals, to collect samples for testing purposes, and to dispense liquids.

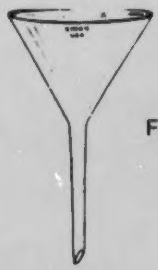


Bottle,
Reagent



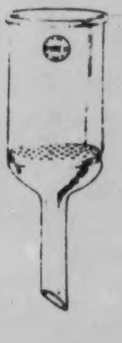
Bottle,
BOD

FUNNELS. A funnel is used for pouring solutions or transferring solid chemicals. This funnel also can be used with filter paper to remove solids from a solution.



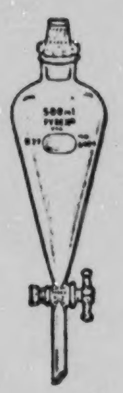
Funnel

A Buchner funnel is used to separate solids from a mixture. It is used with a filter flask and a vacuum.



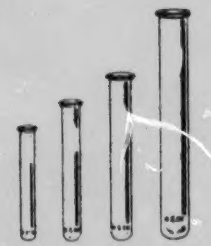
Funnel,
Buchner
With
Perforated Plate

Separatory funnels are used to separate one chemical mixture from another. The separated chemical usually is dissolved in one or two layers of liquid.

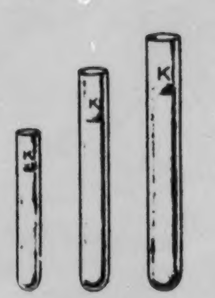


Separatory Funnel

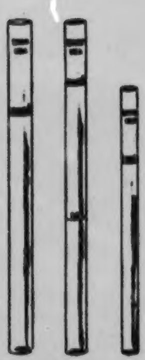
TUBES. Test tubes are used for mixing small quantities of chemicals. They are also used as containers for bacterial testing (culture tubes).



Test Tube



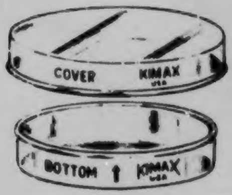
Culture Tube
Without Lip



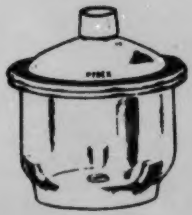
Color Comparison
Tubes, Nessler

OTHER LABWARE AND EQUIPMENT.

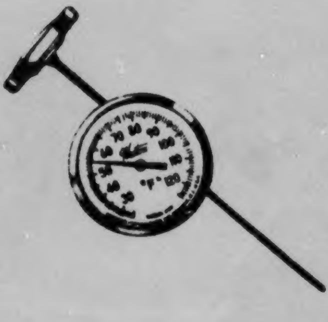
Condenser



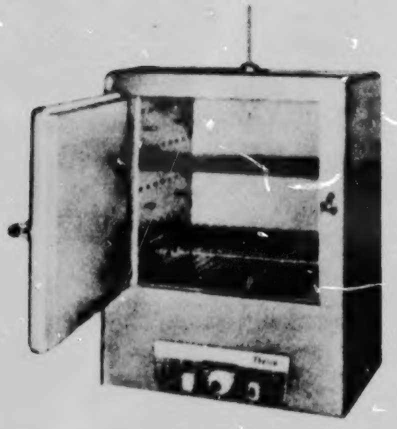
Dish, Petri



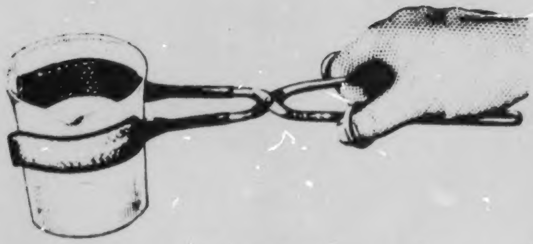
Desiccator
(DESS-uh-KAY-tor)



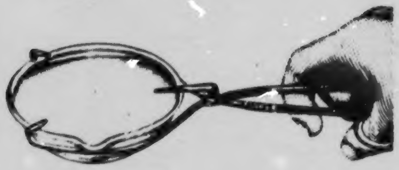
Thermometer, Dial



Oven, Mechanical Convection

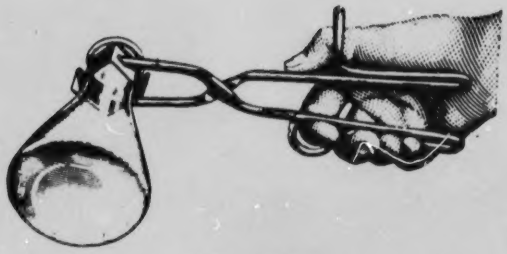


Clamp, Beaker, Safety Tongs

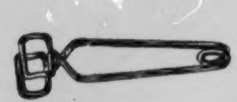


Clamp, Dish, Safety Tongs

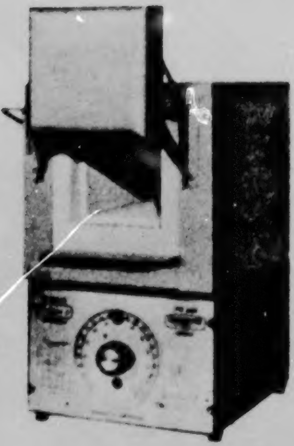
Hot Plate



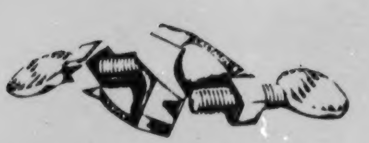
Clamp, Flask, Safety Tongs



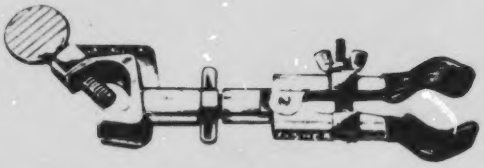
Clamp, Test Tube

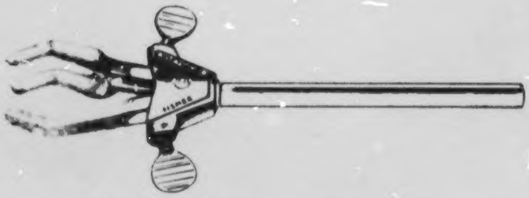


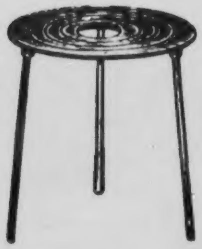
Muffle Furnace, Electric

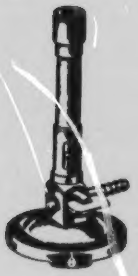


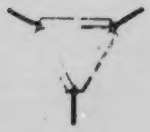
Clamp Holder

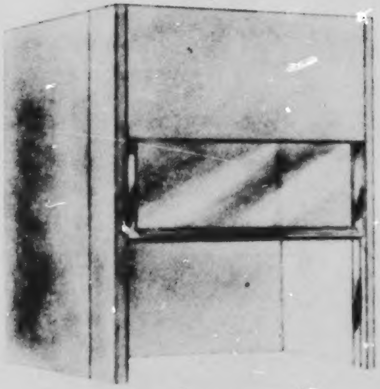

Clamp, Utility


Clamp

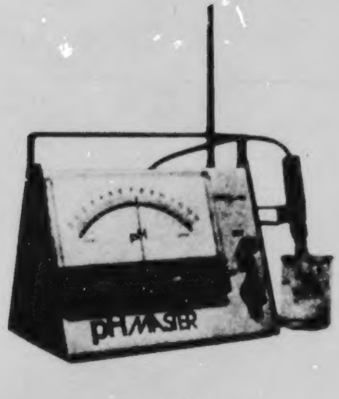

Tripod, Concentric Ring


Burner, Bunsen

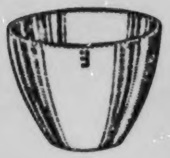

Triangle, Fused


Fume Hood

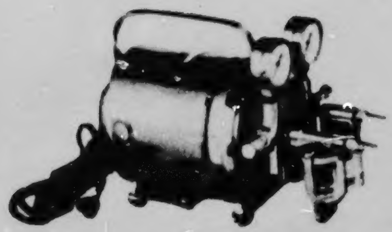
Dissolved Oxygen Meter



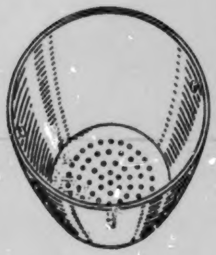
pH Meter



Crucible, (CREW-suh-bull), Porcelain

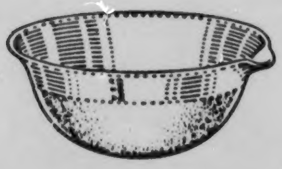


Pump, Air Pressure & Vacuum



Crucible, Gooch (GOO-ch) Porcelain

Pipet Bulb



Dish, Evaporating

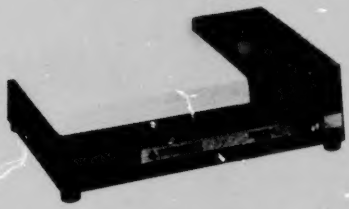
HACH
MODEL 2100A
TURBIDIMETER

Turbidimeter
Permission of Hach Company

pHydrion
Papers
pH1 3 5 7 9 11

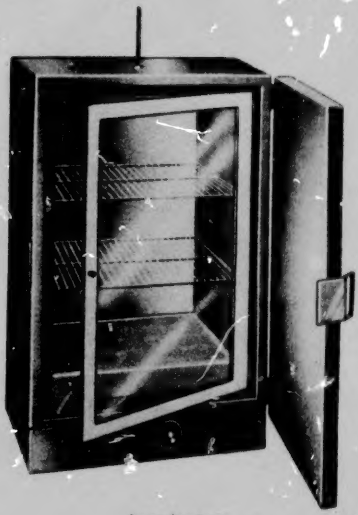
Test Paper, pH 1-11

Ratio turbidimeter
(Permission of Hach Company)



Magnetic stirrer
(Permission of Thermolyne)

Autoclave
(Permission of Napco)

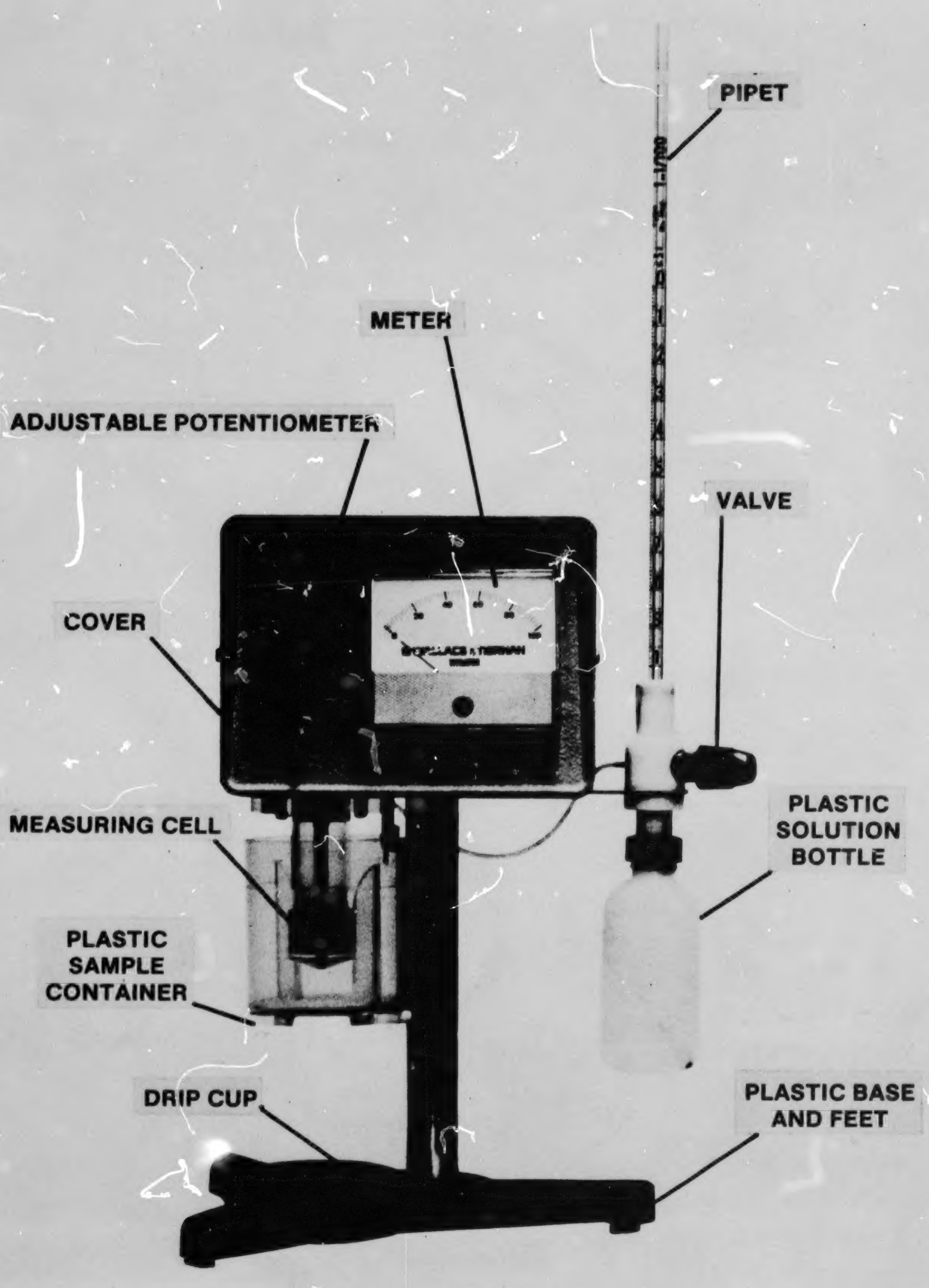


Incubator
(Permission of Blue M Electric)

Color comparator
(Permission of Hellige Co.)

HACH dr/2 spectrophotometer

Spectrophotometer
(Permission of Hach)


PIPET
METER
ADJUSTABLE POTENTIOMETER
VALVE
COVER
MEASURING CELL
PLASTIC SOLUTION BOTTLE
PLASTIC SAMPLE CONTAINER
DRIP CUP
PLASTIC BASE AND FEET

Amperometric titrator

(Permission of Wallace & Tiernan Division, Pennwalt Corporation)

Mettler
0 9 5
65
60
55
10
5
0

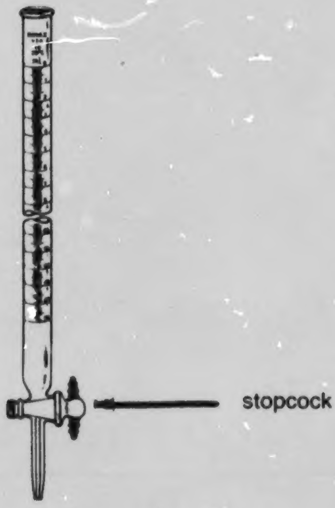
Weight = 95.5580 gm.

Balance, Analytical
(Permission of Mettler)

11.11 Use of Laboratory Glassware

BURETS

A buret is used to give accurate measurements of liquid volumes. The stopcock controls the amount of liquid which will flow from the buret. A glass stopcock must be lubricated (stopcock grease) and should not be used with alkaline solutions. A teflon stopcock never needs to be lubricated.



BURET

Burets come in several sizes, with those holding 10 to 25 milliliters used most frequently.

When a buret is filled with liquid, the surface of the liquid is curved. This curve of the surface is called the meniscus (me-NIS-cuss). Depending on the liquid, the curve may be up, as with mercury, or down as with water. Since most solutions used in the laboratory are water-based, always read the bottom of the meniscus with your eye at the same level (Fig. 11.1). If you have the meniscus at eye level, the closest marks that go all the way around the buret will appear as straight lines, not circles.

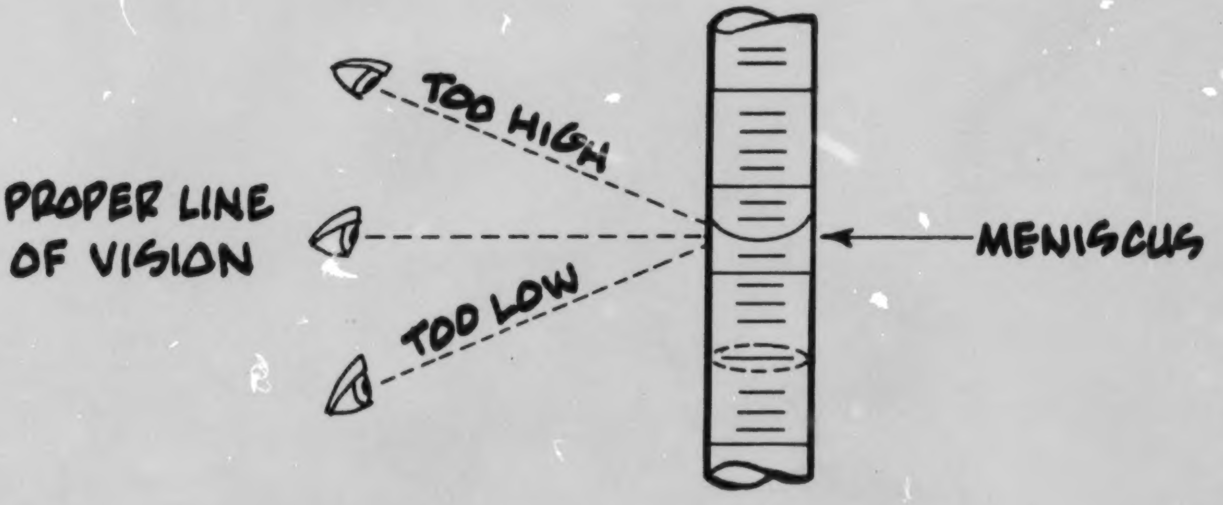
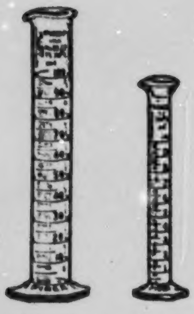


Fig. 11.1 How to read meniscus

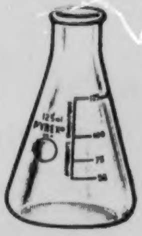


GRADUATED CYLINDERS

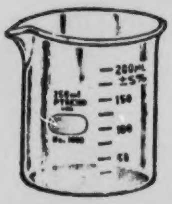
The graduated cylinder or "graduate" is one of the most often used pieces of laboratory equipment. This cylinder is made either of glass or of plastic and ranges in sizes from 10 m*L* to 4 liters. The graduate is used to measure volumes of liquid with an accuracy *LESS* than burets but *GREATER* than beakers or flasks. Graduated cylinders should never be heated in an open flame because they will break.

FLASKS AND BEAKERS

Beakers and flasks are used for mixing, heating, and weighing chemicals. Most beakers and flasks are *NOT* calibrated with exact volume lines; however, they are sometimes marked with approximate volumes and can be used to estimate volumes.



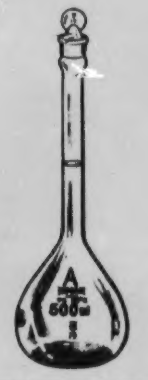
Flask



Beaker

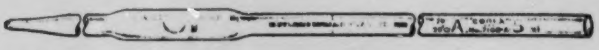
VOLUMETRIC FLASKS

Volumetric flasks are used to prepare solutions and come in sizes from 10 to 2000 m*L*. Volumetric flasks should *NEVER* be heated. Rather than store liquid chemicals in volumetric flasks, the chemicals should be transferred to a storage bottle.

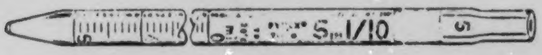


PIPETS

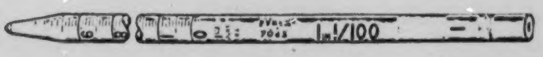
Pipets are used for accurate volume measurements and transfer. There are three types of pipets commonly used in the laboratory — volumetric pipets, graduated or Mohr pipets, and serological pipets.



Volumetric Pipet



Graduated Pipet



Serological Pipet

Volumetric pipets are available in sizes such as 1, 10, 25, 50, and 100 m*L*. They are used to deliver a single volume. Measuring and serological pipets, however, will deliver fractions of the total volume indicated on the pipet.

In emptying volumetric pipets, they should be held in a vertical position and the outflow should be unrestricted. The tip should be touched to the wet surface of the receiving vessel and kept in contact with it until the emptying is complete. Under no circumstance should the small amount remaining in the tip be blown out.

Measuring and serological pipets should be held in the vertical position. After outflow has stopped, the tip should be touched to the wet surface of the receiving vessel. No drainage period is allowed. Where the small amount remaining in the tip is to be blown out and added, this will be indicated by a frosted band near the top of the pipet.

Use of a pipet filler or pipet bulb (page 471) is recommended to draw the sample into a pipet. Never pipet chemical reagent solutions or unknown water samples by mouth. Use the following techniques for best results.

1. Draw liquid up into the pipet past the calibration mark.
2. Quickly remove the bulb and place dry finger tip over the end of the pipet.
3. Wipe excess liquid from the tip of the pipet using laboratory tissue paper.
4. Lift finger and allow desired amount, or all, of liquid to drain.

ACKNOWLEDGMENTS.

Pictures of laboratory glassware and equipment in the manual are reproduced with the permission of VWR Scientific, San Francisco, California, with exceptions noted.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 522.

11.1A For each type of glassware listed below, describe the item and its use or purpose.

1. Beaker
2. Graduated cylinders
3. Pipets
4. Burets

11.1B Why should graduated cylinders never be heated in an open flame?

11.1C What is a meniscus?

11.12 Chemical Solutions

Many laboratory procedures do not give the concentrations of standard solutions in grams/liter or milligrams/liter. Instead, the concentrations are usually given as *NORMALITY (N)*,[1] which is the standard designation for solution strengths in chemistry.

EXAMPLES:

0.025 *N* H_2SO_4 means a 0.025 normal solution of sulfuric acid

2 *N* NaOH means that the normality of a sodium hydroxide solution is 2

The LARGER the number in front of the *N*, the MORE concentrated the solution. For example, 1 *N* NaOH solution is more concentrated than a 0.2 *N* NaOH solution.

Another method of specifying the concentration of solutions uses the "a + b system." This means that "a" volumes of concentrated reagent are diluted with "b" volumes of distilled water to form the required solution.

EXAMPLES:

1 + 1 HCl means 1 volume of concentrated HCl is diluted with 1 volume of distilled water

1 + 5 H_2SO_4 means 1 volume of concentrated sulfuric acid is diluted with 5 volumes of distilled water

When the exact concentration of a prepared chemical solution is known, it is referred to as a "standard solution." Many times standard solutions can be ordered already prepared from chemical supply companies. Once a standard has been prepared, it can then be used to standardize other laboratory solutions. To standardize a solution means to determine and adjust its concentration accurately, thereby making it a standard solution. "Standardization" is the process of using one solution of known concentration to determine the concentration of another solution. This action often involves a procedure called a "titration."

When preparing standard solutions or reagents, the directions may say to weigh out 7.6992 grams of a chemical and dilute to one liter with distilled water. To weigh out 7.6992 grams of a chemical, determine the weight of a weighing dish and add this weight to the weight of the chemical. Place the weighing dish on the weighing platform of an analytical balance. (See page 474. Some balances have the weighing platform on top for the weighing dish.) Gently add the chemical to the weighing dish until you are slightly below the desired weight. The weighing mechanism should be off while the chemical is being added and then turned on to determine the exact weight. When you get close to the exact weight, place some of the chemical on a spatula. Gently tap the spatula to add very small amounts of chemical to the weighing dish. Continue this procedure until you've reached the exact weight. If you add too much chemical, remove some of the chemical with the spatula and again repeat the procedure until you reach the exact weight.

Another procedure is to place approximately the desired weight in the weighing dish. Weigh this amount exactly. Then add a proportionate amount of distilled water.

EXAMPLE 1

The directions for preparing a standard reagent indicate that you should weigh out 7.6992 grams and dilute to one liter. You weigh out 7.5371 grams. How much water should be added to produce the desired concentration or normality of the standard reagent?

KNOWN	UNKNOWN
Desired Weight, gm = 7.6992 gm	Water, m*L*
Actual Weight, gm = 7.5371 gm	

The chemical should be diluted to how many milliliters?

$$\text{Dilute to } mL = \frac{(\text{Actual Weight, gm})(1000\ mL)}{(\text{Desired Weight, gm})}$$

$$= \frac{(7.5371\ \text{gm})(1000\ mL)}{(7.6992\ \text{gm})}$$

$$= 979\ mL$$

The 7.5371 grams of chemical should be diluted to 979 m*L*.

11.13 Titrations

A titration involves the measured addition of a standardized solution, which is generally in a buret, to another solution in a flask or beaker. The solution in the buret, is referred to as the "titrant" and is added to the other solution until there is a measurable change in the test solution in the flask or beaker. This change is frequently a color change as a result of the addition of another chemical called an "indicator" to the solution in the flask before the titration begins. The solution in the buret is added slowly to the flask until the change, which is called the "end point," is reached. The entire process is the "titration." Figure 11.2 illustrates the four general steps used during a chemical titration.

---

[1] *Normal. A normal solution contains one gram equivalent weight of a reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A 1 N solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.*

11.14 Data Recording and Recordkeeping

The use of a laboratory notebook and worksheets are a must for laboratory analysts, water supply system and treatment plant operators. Notebooks and worksheets help you record data in an orderly manner. Too often, hours of work are wasted when test results and other data (such as a sample volume) are written down on a scrap of paper only to be misplaced or thrown away by mistake. Notebooks and worksheets help prevent error and provide a record of your work. The routine use of laboratory worksheets and notebooks is the only way an operator or a lab person can be sure that all important information is properly recorded.

There is no standard laboratory form. Most operators usually develop their own data sheets for recording test results and other important data. These data sheets should be prepared in a manner that makes it easy for you to record results, review them, and recover these results when it is necessary. Each treatment plant will have different needs for collecting and recording data and may require several different data or worksheets. Figures 11.3 and 11.4 illustrate two typical laboratory worksheets.

11.15 Laboratory Quality Control

Having good equipment and using the correct methods are not enough to insure correct analytical results. Each operator must be constantly alert to factors in the water treatment process which can lead to poor quality of data. Such factors include sloppy laboratory technique, deteriorated reagents and standards, poorly operating instruments, and calculation mistakes. One of the best ways to insure quality control in your laboratory is to analyze reference-type samples to provide independent checks on your analysis. These reference-type samples are available from the U.S. Environmental Protection Agency and from commercial sources. From time to time, it is also a good idea to split a sample with one of your fellow operators or another laboratory and compare analytical results. In addition, frequent self-appraisal and evaluation — from sampling to reporting results — can help you gain full confidence in your results.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 522.

11.1D What is a "standard solution?"

11.1E What is the primary purpose of laboratory notebooks and worksheets?

11.1F List three sources or causes of poor quality of analytical data.

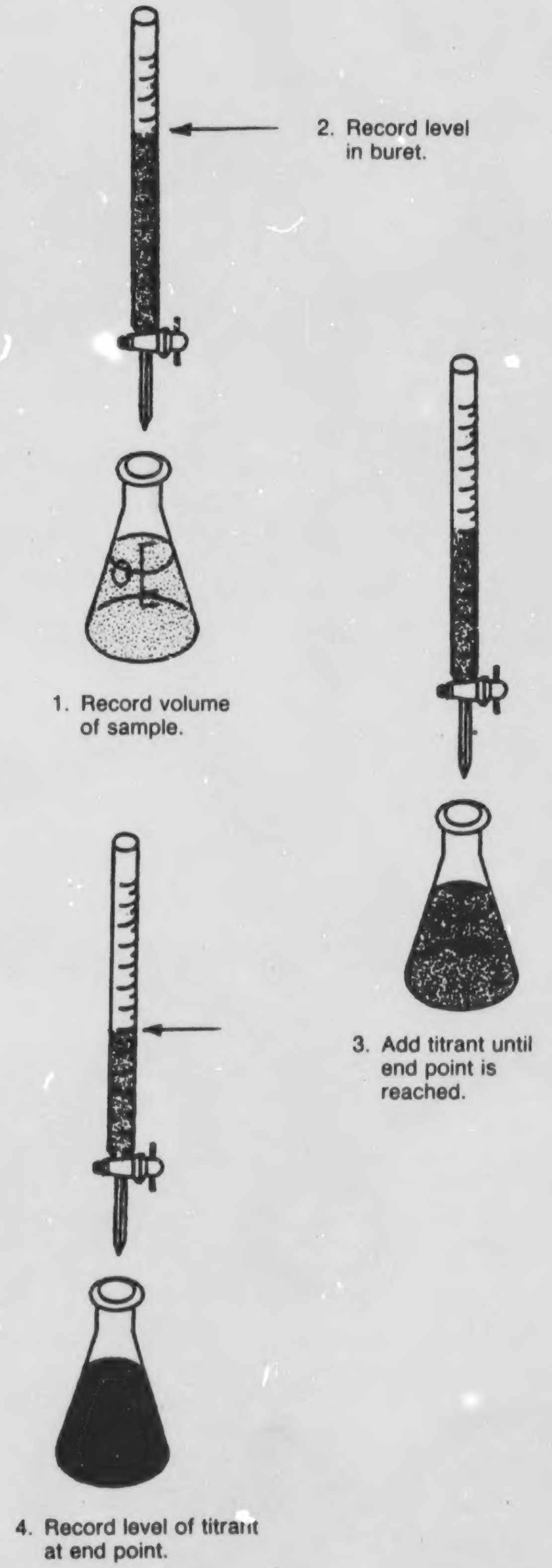

2. Record level in buret.
1. Record volume of sample.
3. Add titrant until end point is reached.
4. Record level of titrant at end point.

Fig. 11.2 Titration steps

WATER ANALYSES REPORT SHEET

(All results in mg/*L* except as noted)

SAMPLE SOURCE:			
DATE SAMPLED:	BY:		
ANALYST:	DATE COMPLETED:		
A. PHYSICAL PARAMETERS	METHODS INDEX		
color (units)	Std. Methods pg. 61		
odor (units)	Std. Methods pg. 78		
turbidity (NTU)	Std. Methods pg. 132		
B. GENERAL MINERAL pH (units)	METHODS INDEX Std. Methods pg. 402		
total alkalinity ($CaCO_3$)	Std. Methods pg. 253		
Specific conductance μmhos/cm	Std. Methods pg. 70		
total dissolved residue	Std. Methods pg. 94		
total hardness ($CaCO_3$)	Std. Methods pg. 195		
calcium	Std. Methods pg. 183		
magnesium	Std. Methods pg. 211		
iron	Std. Methods pg. 201		
manganese	Std. Methods pg. 214		
chloride	Std. Methods pg. 271		
sulfate	Std. Methods pg. 439		

Fig. 11.3 Typical laboratory worksheet

11.16 Laboratory Safety

Safety is just as important in the laboratory as it is outside the lab. State laws and the Occupational Safety and Health Act (OSHA) demand that proper safety procedures be exercised in the laboratory at all times. OSHA specifically deals with "safety at the place of work." The Act requires that "each employer has the general duty to furnish all employees with employment free from recognized hazards causing, or likely to cause, death or serious physical harm."

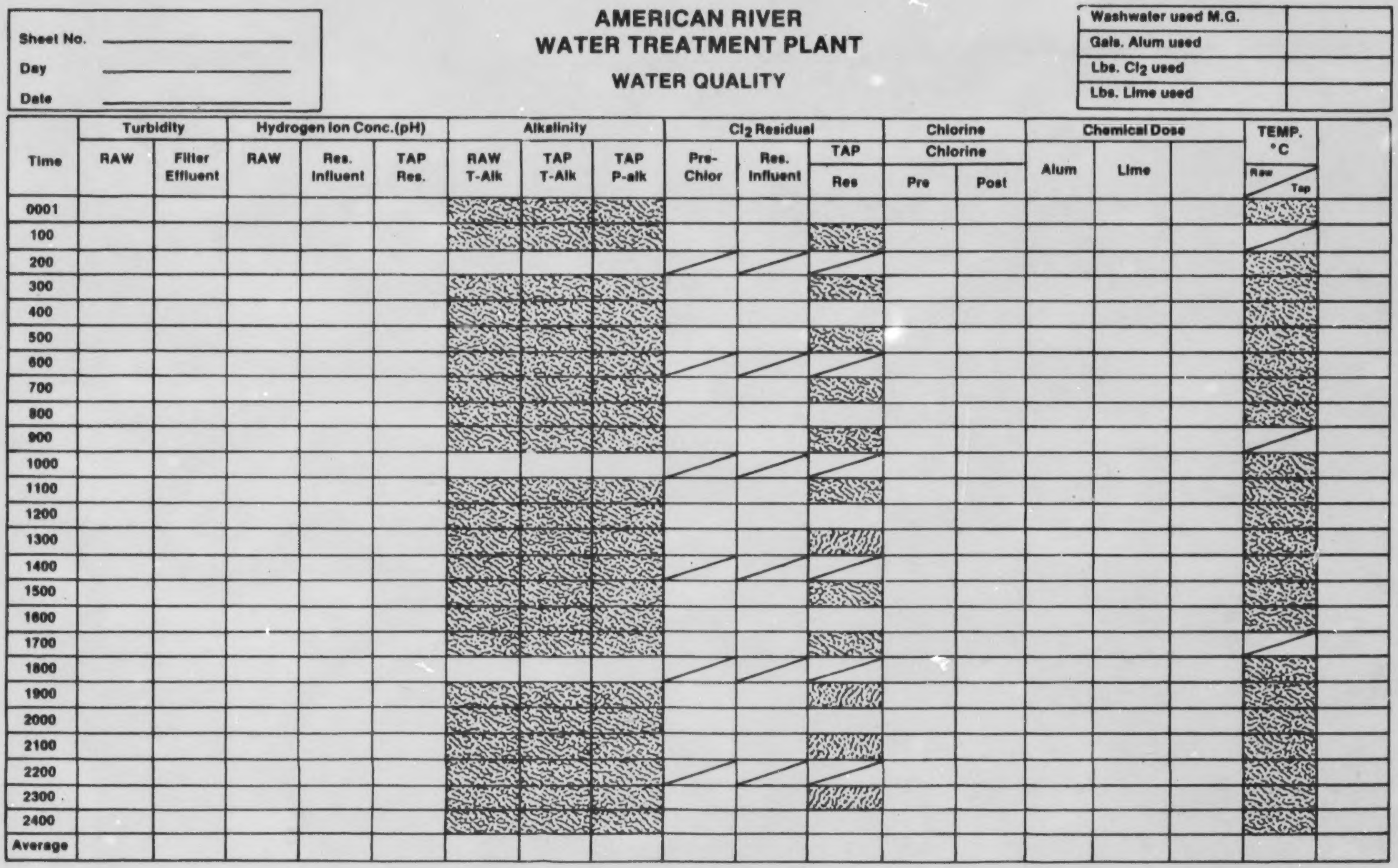
Personnel working in the water industry must realize that a number of hazardous materials and conditions can exist. Always be alert and careful. Be aware of potential dangers at all times. Safe practice in the laboratory and anytime while working around chemicals requires hardly any more effort than unsafe practices, with the important benefits from prevention of injury to you and your fellow operators.

On specific questions of safety, consult your state's General Industrial Safety Orders or OSHA regulations.

11.160 Laboratory Hazards

Working with chemicals and other materials in the water laboratory can be dangerous. Laboratory hazards include:

1. Hazardous materials,
2. Explosions,
3. Cuts and bruises,
4. Electrical shock,
5. Fire, and
6. Burns (heat and chemical).



Sheet No.	
Day	
Date	

AMERICAN RIVER WATER TREATMENT PLANT

WATER QUALITY

Washwater used M.G.	
Gals. Alum used	
Lbs. Cl_2 used	
Lbs. Lime used	

Time	Turbidity		Hydrogen Ion Conc.(pH)			Alkalinity			Cl_2 Residual			Chlorine		Chemical Dose			TEMP. °C	
											TAP	Chlorine						
	RAW	Filter Effluent	RAW	Res. Influent	TAP Res.	RAW T-Alk	TAP T-Alk	TAP P-alk	Pre-Chlor	Res. Influent	Res	Pre	Post	Alum	Lime		Raw / Tap	
0001						▨	▨	▨									▨	
100						▨	▨	▨			▨						╱	
200									╱	╱	╱						▨	
300						▨	▨	▨			▨						▨	
400						▨	▨	▨									▨	
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2400						▨	▨	▨									▨	
Average																		

Fig. 11.4 Typical operational worksheet

Hazardous materials include (1) corrosive, (2) toxic, and (3) explosive or flammable materials.

1. Corrosive Materials

   ACIDS

   a. Examples: Hydrochloric or muriatic (HCl), hydrofluoric (HF), glacial acetic (CH_3COOH), nitric (NHO_3), and sulfuric (H_2SO_4).

   b. Acids can be extremely corrosive and hazardous to human tissue, metals, clothing, cement, stone, and concrete.

   c. Commercially available spill clean-up kits should be kept on hand to neutralize the acid in the event of an accidental spill. Baking soda (bicarbonate, *NOT* laundry soda) effectively neutralizes acids. Baking soda can be used on lab and human surfaces without worrying about toxicity.

   BASES (Caustics)

   a. Examples: Sodium hydroxide (caustic soda or lye, NaOH), quick lime (CaO), hydrated lime ($Ca(OH)_2$), and alkaline iodine-azide solution (used in dissolved oxygen test).

   b. Bases are extremely corrosive to skin, clothing, and leather.

   c. Commercially available spill clean-up materials should be kept on hand for use in the event of an accidental spill. A jug of cheap vinegar can be kept on hand to neutralize bases and will not harm your skin.

   MISCELLANEOUS CHEMICALS

   a. Examples: Alum, chlorine, ferric salts (ferric chloride), and other strong oxidants.

2. Toxic Materials

   Examples:

   a. Solids: Cyanide compounds, chromium, orthotolidine, cadmium, mercury, and other heavy metals.

   b. Liquids: Chloroform and other organic solvents.

   c. Gases: Chlorine, ammonia, sulfur dioxide, and chlorine dioxide.

3. Explosive or Flammable Materials

   Examples:

   a. Liquids: Acetone, ethers, and gasoline.

   b. Gases: Propane and hydrogen.

11.161 Personal Safety and Hygiene

Laboratory work can be quite dangerous if proper precautions and techniques are not taken. *ALWAYS* follow these basic rules:

1. *NEVER* work all alone in the laboratory. Someone should always be available to help in case you should have an accident which blinds you, leaves you unconscious, or starts a fire you can't handle. If necessary have someone check on you regularly to be sure you are OK.
2. Wear protective goggles or eye glasses at all times in the laboratory. Contact lenses should not be worn, even under safety goggles, because fumes can seep between the lens and the eyeball and irritate the eye.
3. Never pipet hazardous materials by your mouth.

Safety Glasses

DON'T PIPET HAZARDOUS LIQUIDS BY MOUTH.

4. Always wear a lab coat or apron in the laboratory to protect your skin and clothes.
5. Wear asbestos gloves when handling hot objects. If there is a danger of hot liquid erupting from a container, wear a face shield, too.
6. Don't keep food in a refrigerator that is used for chemical and/or sample storage.
7. Good housekeeping is an effective way to prevent accidents.

11.162 Prevention of Laboratory Accidents

11.1620 Chemical Storage An adequate chemical storeroom is essential for safety in the water laboratory. The storeroom should be properly ventilated and lighted and be laid out to segregate incompatible chemicals. Order and cleanliness must be maintained. Clearly label and date all chemicals and bottles or reagents.

Store heavy items on or as near to the floor as possible. *VOLATILE LIQUIDS*[2] which may escape as a gas, such as ether, must be kept away from heat sources, sunlight, and electrical switches.

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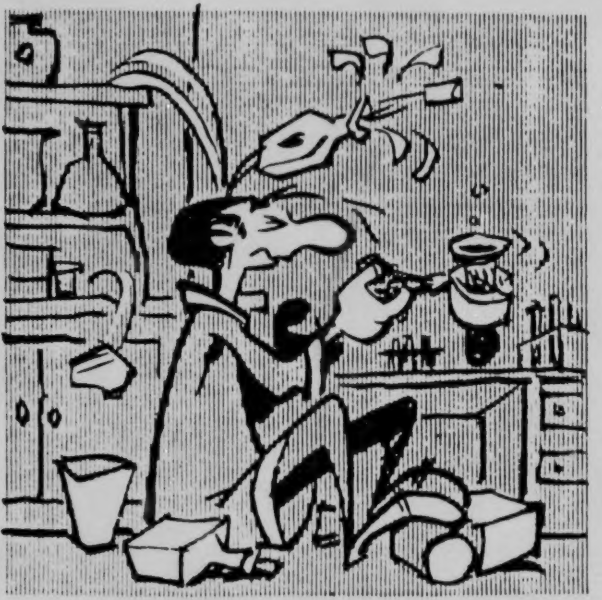
[2] *Volatile Liquids (VOL-uh-tull). Liquids which easily vaporize or evaporate at room temperature.*

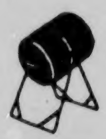


CLAMPS, RAISED SHELF EDGES AND PROPER ARRANGEMENT PREVENT STOCKROOM FALLOUT.

Cap and secure cylinders of gas in storage to prevent rolling or tipping. They should also be placed away from any possible sources of heat or open flames.

Follow usual common sense rules of storage. Good housekeeping is a most significant contribution toward an active safety campaign.

11.1621 Movement of chemicals The next area of concern is the transfer of chemicals, apparatus, gases, or other hazardous materials from the storeroom to the laboratory for use. Use cradles or tilters to facilitate handling, carboys or other larger chemical vessels.



Drum Tilter

In transporting cylinders of compressed gases, use a trussed handtruck. Never roll a cylinder by its valve. Immediately after they are positioned for use, cylinders should be clamped securely into place to prevent shifting or toppling.

Carry flammable liquids in safety cans or, in the case of reagent-grade chemicals, protect the bottle with a carrier. Always wear protective gloves, safety shoes, and rubber aprons in case of accidental spilling of chemical containers.

11.1622 Proper laboratory techniques Faulty technique is one of the chief causes of accidents and, because it involves the human element, is one of the most difficult to correct.

Because of their nature and prevalence in the laboratory, acids and other corrosive materials constitute a series of hazards ranging from poisoning, burning, and gassing through explosion. Always flush the outsides of acid bottles with water before opening them. Don't lay the stopper down on the counter top where a person might lay a hand or rest an arm on it. Keep all acids tightly stoppered when not in use and make sure no spilled acid remains on the floor, table, or bottle after use. To avoid splashing of acid, don't pour water into acid; ALWAYS POUR ACID INTO WATER.

Mercury requires special care. Even a small amount in the bottom of a drawer can poison the atmosphere in a room. After an accident involving mercury, go over the entire area carefully until there are no globules remaining. Keep all mercury containers well-stoppered.

11.1623 Accident prevention *ELECTRICAL SHOCK.* Wherever there are electrical outlets, plugs, and wiring connections, there is a danger of electrical shock. The usual "do's" and "don'ts" of protection against shock in the home are equally applicable in the laboratory. Don't use worn or frayed wires. Replace connections when there is any sign of thinning insulation. Ground all apparatus using three-prong plugs. Don't continue to run a motor after liquid has spilled on it. Turn it off immediately and clean and dry the inside thoroughly before attempting to use it again.

Electrical units which are operated in an area exposed to flammable vapors should be explosion proof. All permanent wiring should be installed by an electrician with proper conduit or BX cable to eliminate any danger of circuit overloading.

CUTS. Some of the pieces of glass used in the laboratory, such as glass tubing, thermometers, and funnels, must be inserted through rubber stoppers. If the glass is forced through the hole in the stopper by applying a lot of pressure, the glass usually breaks. This is one of the most common sources of cuts in the laboratory.

Use care in making rubber-to-glass connections. Lengths of glass tubing should be supported while they are being inserted into rubber. The ends of the glass should be *FLAME POLISHED*[3] and either wetted or covered with a lubricating jelly for ease in joining connections. Never use oil or grease. Wear gloves when making such connections, and hold the tubing as close to the end being inserted as possible to prevent bending or breaking.

Never try to force rubber tubing or stoppers from glassware. Cut off the rubber or materials.

A FIRST-AID kit must be available in the laboratory.

BURNS. All glassware and porcelain look cold after the red from heating has disappeared. The red is gone in seconds but the glass is hot enough to burn for several minutes. After heating a piece of glass, put it out of the way until cold.

Spattering from acids, caustic materials, and strong oxidizing solutions should be washed off immediately with large quantities of water. Every worker in the water laboratory should have access to a sink and an emergency deluge shower. Keep vinegar and soda handy to neutralize acids and bases (caustic materials).

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[3] *Flame Polished. Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.*

Many safeguards against burns are available. Gloves, safety tongs, aprons, and emergency deluge showers are but a few examples. Never decide it is too much trouble to put on a pair of gloves or use a pair of tongs to handle a dish or flask that has been heated.

USE TONGS—DON'T JUGGLE HOT CONTAINERS.

Perhaps the most harmful and painful chemical burn occurs when small objects, chemicals or fumes get into your eyes. Immediately flood your eyes with water or a special "eye wash" solution from a safety kit or from an eyewash station or fountain.

TOXIC FUMES. Use a fumehood for routine reagent preparation. Pick a hood that has adequate air displacement and expels harmful vapors and gases at their source. An annual check should be made of the entire laboratory building. Sometimes noxious fumes are spread by the heating and cooling system of the building.

When working with chlorine and other toxic substances, always wear a self-contained breathing apparatus. If possible, try to clear the atmosphere with adequate ventilation *BEFORE* entry.

WASTE DISPOSAL. A good safety program requires constant care in disposal of laboratory waste. Corrosive materials should never be poured down a sink or drain. These substances can corrode away the drain pipe and/or trap. Corrosive acids should be poured down corrosion-resistant sinks and sewers using large quantities of water to dilute and flush the acid.

To protect maintenance personnel, use separate covered containers to dispose of broken glass.

DON'T POUR VOLATILE LIQUIDS INTO THE SINK.

FIRE. The laboratory should be equipped with a fire blanket. The fire blanket is used to smother clothing fires. Small fires which occur in an evaporating dish or beaker may be put out by covering the container with a glass plate, wet towel, or wet blanket. For larger fires, or ones which may spread rapidly, promptly use a fire extinguisher. Do not use a fire extinguisher on small beaker fires because the force of the spray will knock over the beaker and spread the fire. Take time to become familiar with the operation and use of your fire extinguishers.

The use of the proper type of extinguisher for each class of fire will give the best control of the situation and avoid compounding the problem. The class of fires given here is based on the type of material being consumed.

Class A Fires: (For wood, paper, textiles, and similar materials.) Use foam, water, carbon dioxide gas or almost any kind of extinguisher.

CHOOSE AN EXTINGUISHER BY CLASS OF FIRE---DON'T GUESS.

Class B Fires: (For grease, oil, paint, and related materials.) Use foam, dry chemical or vaporizing liquid extinguishers.

Class C Fires: (All fires in electrical equipment and in areas where live electricity is present.) Use carbon dioxide, dry chemical, or vaporizing liquid extinguishers only.

Class D Fires: (Fires involving sodium, zinc, magnesium, and other elements). These fires should be smothered with fine dry soda ash, sand, or graphite.

11.163 Acknowledgments

Portions of this section were taken from material written by A.E. Greenberg, "Safety and Hygiene," which appeared in the California Water Pollution Control Association's *OPERATORS' LABORATORY MANUAL.* Some of the ideas and material also came from the *FISHER SAFETY MANUAL.*

11.164 Additional Reading

1. *FISHER SAFETY MANUAL.* Available from Fisher Scientific Company, 711 Forbes Avenue, Pittsburgh, PA 15210. Price $6.00.
2. *SAFETY IN THE CHEMICAL LABORATORY.* Edited by Norman V. Steere. 3 Volumes. Price $21.90. Order from Journal of Chemical Education, Office of Publications Coordinator, 238 Kent Road, Springfield, PA 19064.
3. *GENERAL INDUSTRY, OSHA. SAFETY AND HEALTH STANDARDS* (29 CFR 1910), OSHA 2206, revised January 1976. Obtain from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Stock Number 029-015-00054-6. Price $6.50.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 522.

11.1G List five laboratory hazards.

11.1H Why should you not work all alone in a laboratory?

11.1I How would you dispose of a corrosive acid?

11.1J True or False? You may *ADD ACID* to water, but never water to acid.

End of Lesson 1 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. LABORATORY PROCEDURES

(Lesson 1 of 5 Lessons)

At the end of each lesson in this chapter you will find some discussion and review questions that you should work before continuing. The purpose of these questions is to indicate to you how well you understand the material in the lesson. Write the answers to these questions in your notebook.

1. How do the operators of water treatment plants use the results from laboratory tests?
2. Why must chemicals be properly labeled?
3. How are pipets emptied or drained? Why is this procedure important?
4. How would you titrate a test solution?
5. Why should work with certain chemicals be conducted under a ventilated laboratory hood?
6. Why should water not be poured on certain types of fires?
7. List as many of the seven basic rules for working in a laboratory as you can remember.

CHAPTER 11. LABORATORY PROCEDURES

(Lesson 2 of 5 Lessons)

11.2 SAMPLING

11.20 Importance of Sampling

Sampling is a vital part of studying the quality of water in a water treatment process, distribution system, or source of water supply. The major source of error in the whole process of obtaining water quality information often occurs during sampling. This fact is not well enough recognized and cannot be over emphasized.

In any type of testing program where only small samples (a liter or two) are withdrawn from perhaps millions of gallons of water under examination, there is potential uncertainty because of possible sampling errors. Water treatment decisions based upon incorrect data may be made if sampling is performed in a careless and thoughtless manner. Obtaining good results will depend to a great extent upon the following factors:

1. Insuring that the sample taken is truly representative of the water under consideration,
2. Using proper sample techniques, and
3. Protecting and preserving the samples until they are analyzed.

The greatest errors in laboratory tests are usually caused by improper sampling, poor preservation, or lack of enough mixing during testing. The accuracy of your analysis is only as good as the care that was taken in obtaining a representative sample.[4]

11.21 Representative Sampling

11.210 Importance of Representative Sampling

The sampling of a tank or a lake that is completely mixed is a simple matter. Unfortunately, most bodies of water are not well mixed and obtaining samples that are truly representative of the whole body depends to a great degree upon sampling technique. A sample that is properly mixed (integrated) by taking small portions of the water at points distributed over the whole body represents the material better than a sample collected from a single point. The more portions taken, the more nearly the sample represents the original. The sample error would reach zero when the size of the sample became equal to the original volume of material being sampled, but for obvious reasons this method of decreasing sample error is not practical. The size of sample depends on which water quality indicators are being tested and how many. Every precaution must be taken to insure that the sample collected is as representative of the water source or process being examined as is feasible.

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[4] *Representative Sample. A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.*

11.211 Source Water Sampling

RIVERS. To adequately determine the composition of a flowing stream, each sample (or set of samples taken at the same time) must be representative of the entire flow at the sampling point at that instant. Furthermore, the sampling process must be repeated frequently enough to show significant changes of water quality that may occur over time in the water passing the sampling point.

On small or medium-sized streams, it is usually possible to find a sampling point at which the composition of the water is presumably uniform at all depths and across the stream. Obtaining representative samples in these streams is relatively simple. For larger streams, more than one sample may be required. A portable conductivity meter is very useful in selecting good sample sites.

RESERVOIRS AND LAKES. Water stored in reservoirs and lakes is usually poorly mixed. Thermal stratification and associated depth changes in water composition (such as dissolved oxygen) are among the most frequently observed effects. Single samples can therefore be assumed to represent only the spot of water from which the sample came. Therefore, a number of samples must be collected at different depths and from different areas of the impoundment to accurately sample reservoirs and lakes.

GROUNDWATER. Most of the physical factors which promote mixing in surface waters are absent or much less effective in groundwater systems. Wells usually draw water from a considerable thickness of saturated rock and often from several different strata. These water components are mixed by the turbulent flow of water in the well before they reach the surface and become available for sampling. Most techniques for well sampling and exploration are usable only in unfinished or non-operating wells. Usually the only means of sampling the water tapped by a well is the collection of a pumped sample. The operator is cautioned to remember that well pumps and casings can contribute to sample contamination. If a pump has not run for an extended period of time prior to sampling, the water collected may not be representative of the normal water quality.

11.212 In-Plant Sampling

Collection of representative samples within the water treatment plants is really no different from sample collection in a stream or river. The operator simply wants to be sure the water sampled is representative of the water passing that sample point. In many water plants, money is spent to purchase sample pumps and piping only to sample from a point that is not representative of the passing water. A sample tap in a dead area of a reservoir or on the floor of a process basin serves no purpose in helping the plant operator with control of water quality. The operator is urged to find each and every sample point and insure it is located to provide a useful and representative sample. If the sampling point is not properly located, plan to move the piping to a better location.

11.213 Distribution System Sampling

Representative sampling in the distribution system is a true indication of system water quality. Results of sampling should show if there are quality changes in the entire, or parts of, the system and may point to the source of a problem (such as tastes and/or odors). Sampling points should be selected, in part, to trace the course from finished water source (at the well or plant) through the transmission mains, and then through the major and minor arteries of the system. A sampling point on a major artery, or on an active main directly connected to it, would be representative of the water quality being furnished to a subdivision of this network. Generally, these primary points are used as "official" sample points in evaluating prevailing water quality.

Obtaining a representative sample from the distribution system is not as easy as it might seem. One would think almost any faucet would do, but experience has shown otherwise. Local conditions at the tap and in its connection to the main can easily make the point unrepresentative of water being furnished to your consumers.

The truest evaluation of a water sample can be obtained from samples drawn directly from the main. You might think that samples taken from a fire hydrant would prove satisfactory, but this is usually not the case. The problem with fire hydrants as sampling points is that they give erratic (uneven) results due to the way they are constructed and their lack of use. In general, an ideal sample station is one that has a short, direct connection with the main and is made of corrosion-resistant material.

FREE
SAMPLES
TAKE ONE

In most smaller water systems, special sample taps are not available. Therefore, customer's faucets must be used to collect samples. The best sample points are front yard faucets on homes supplied by short service lines (homes with short service lines are located on the same side of the street as the water main).

If the customer is home, you should contact the person in the home and obtain permission to collect the sample. Disconnect the hose from the faucet if one is attached and don't forget to reconnect the hose when finished collecting the sample. Open the faucet to a convenient flow for sampling (usually about half a gallon per minute). Allow the water to flow until the water in the service line has been replaced twice. Since 50 feet (15 m) of three-quarter inch (18 mm) pipe contains over one gallon (3.8 liters), four or five minutes will be required to replace the water in the line twice. Collect the sample. Be sure the sample container does not touch the faucet.

Do not try to save time by turning the faucet handle to wide open to flush the service line. This will disturb sediment and incrustations in the line which must be flushed out before the sample can be collected.

FORMULAS

To estimate the flow from a faucet, use a gallon jug and a watch. If you want a flow of half a gallon per minute, then the jug should be half full in one minute or completely full in two minutes.

$$\text{Flow, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

To calculate the volume of a service line, multiply the area of the pipe in square feet times the length of the pipe in feet to obtain cubic feet. The diameter of a pipe is given in inches, so this value must be divided by 12 inches per foot to obtain a volume in cubic feet. Multiply cubic feet by 7.48 gallons per cubic foot to obtain the volume in gallons.

$$\text{Pipe Volume, cu ft} = \frac{(\text{Pipe Area, sq in})(\text{Pipe Length, ft})}{144 \text{ sq in/sq ft}}$$

$$\text{Pipe Volume, gal} = (\text{Pipe Volume, cu ft})(7.48 \text{ gal/cu ft})$$

To determine the time to allow water to flow from a faucet to flush a service line twice, divide the pipe volume in gallons by the flow in gallons per minute. Then multiply the result by two so the line will be flushed twice.

$$\text{Flushing Time, min} = \frac{(\text{Pipe Volume, gal})(2)}{\text{Flow, gal/min}}$$

EXAMPLE 2

How long should a three-quarter inch service line 80 feet long be flushed if the flow is 0.5 GPM?

KNOWN	**UNKNOWN**
Diameter, in = ¾ in = 0.75 in	Flushing Time, min
Length, ft = 80 ft	
Flow, GPM = 0.5 GPM	

Calculate the pipe volume in cubic feet and then in gallons.

$$\begin{aligned}\text{Pipe Volume, cu ft} &= \frac{(\text{Pipe Area, sq in})(\text{Pipe Length, ft})}{144 \text{ sq in/sq ft}}\\ &= \frac{(0.785)(0.75 \text{ in})^2(80 \text{ ft})}{144 \text{ sq in}}\\ &= 0.245 \text{ cu ft}\end{aligned}$$

$$\begin{aligned}\text{Pipe Volume, gal} &= (\text{Pipe Volume, cu ft})(7.48 \text{ gal/cu ft})\\ &= (0.245 \text{ cut ft})(7.48 \text{ gal/cu ft})\\ &= 1.833 \text{ gal}\end{aligned}$$

Calculate the flushing time for the service line in minutes.

$$\begin{aligned}\text{Flushing Time, min} &= \frac{(\text{Pipe Volume, gal})(2)}{\text{Flow, gal/min}}\\ &= \frac{(1.833 \text{ gal})(2)}{0.5 \text{ GPM}}\\ &= 7.3 \text{ min}\\ \text{or} \quad &= 7 \text{ min} + (0.3 \text{ min})(60 \text{ sec/min})\\ &= 7 \text{ min and } 18 \text{ sec}\end{aligned}$$

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 522.

11.2A What are frequently the greatest causes of errors in laboratory tests?

11.2B Why must a representative sample be collected?

11.2C How are sampling points selected in a distribution system?

11.22 Types of Samples

There are generally two types of samples collected by waterworks operators, and either type may be obtained manually or automatically. The two types are grab samples and composite samples.

11.220 Grab Samples

A grab sample is a single water sample collected at no specific time. Grab samples will show the water characteristics at the time the sample was taken. A grab sample may be preferred over a composite sample when:

1. The water to be sampled does not flow on a continuous basis,
2. The water's characteristics are relatively constant, and
3. The water is to be analyzed for water quality indicators that may change with time, such as dissolved gases, coliform bacteria, residual chlorine, temperature, and pH.

11.221 Composite Samples

In many processes, the water quality is changing from moment to moment or hour to hour. A continuous sampler-analyzer would give the most accurate results in these cases. However, since operators themselves are often the sampler-analyzer, continuous analysis would leave little time for anything but sampling and testing. Except for tests which cannot wait due to rapid physical, chemical, or biological changes of the sample (such as tests for dissolved oxygen, pH, and temperature) a fair compromise may be reached by taking samples throughout the day at hourly or two-hour intervals. Each sample should be refrigerated immediately after it is collected. At the end of 24 hours, a portion of each sample is mixed with the other samples. The size of the portion is in direct proportion to the flow when the sample was collected and the total size of sample needed for testing. For example, if hourly samples were collected, when the flow was 1.2 MGD, use a 12 m*L* portion sample and when the flow was 1.5 MGD, use a 15 m*L* portion of the sample. The resulting mixture of portions of samples is called a *COMPOSITE SAMPLE.* In no case, however, should a composite sample be collected for bacteriological examination.

When the samples are taken, they can either be set aside to be combined later or combined as they are collected. In both cases, they should be stored at a temperature of 4°C until they are analyzed.

11.23 Sampling Devices

Automatic sampling devices are wonderful time-savers but are expensive. As with anything automatic, problems do arise and the operator should be on the look out for potential difficulties.

Manual sampling equipment includes dippers, weighted bottles, hand-operated pumps, and cross-section samplers. Dippers consist of wide-mouth corrosion-resistant containers (such as cans or jars) on long handles that collect a sample for testing. A weighted bottle is a collection container which is lowered to a desired depth. At this depth a cord or wire removes the bottle stopper so the bottle can be filled (see Figure 11.5).

Some water treatment facilities use sample pumps to collect the sample and transport it to a central location. The pump and its associated piping should be corrosion-resistant and sized to deliver the sample at a high enough velocity to prevent sedimentation in the sample line.

Many water agencies have designed and installed special sampling stations throughout their distribution systems (see Figure 11.6). These stations provide an excellent location to sample the actual quality of water in your distribution system.

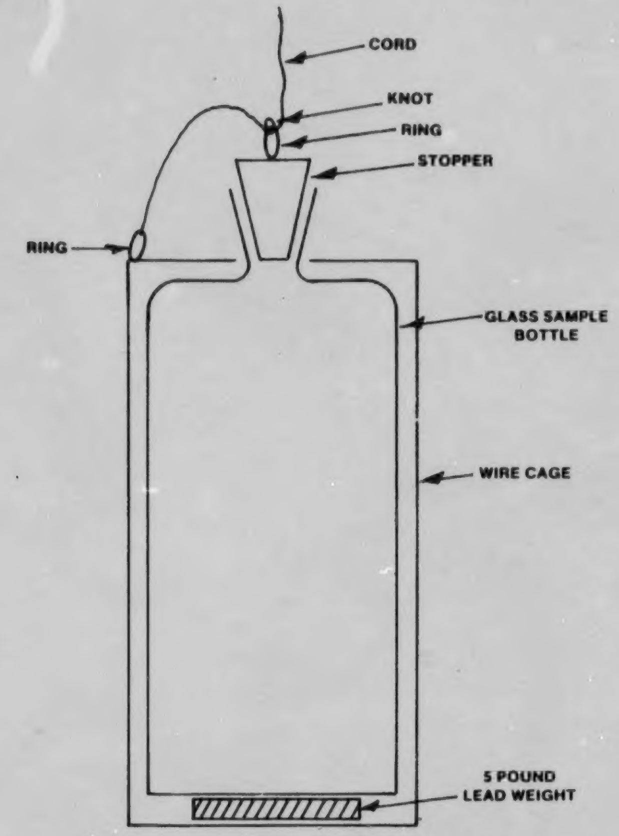


Fig. 11.5 Sectional view of home-made depth sampler

11.24 Sampling Techniques

11.240 Surface Sampling

A surface sample is obtained by grasping the sample container at the base with one hand and plunging the bottle mouth-down into the water to avoid introducing any material floating on the surface. Position the mouth of the bottle into the current and away from the hand of the collector (see Figure 11.7). If the water is not flowing, then an artificial current can be created by moving the bottle horizontally in the direction it is pointed and away from the sampler. Tip the bottle slightly upwards to allow air to exit so the bottle can fill. Tightly stopper and label the bottle.

Place the bottle in a weighted frame that holds the bottle securely when sampling from a walkway or other structure above a body of water. Remove the stopper or lid and lower the device to the water surface. A nylon rope which does not absorb water and will not rot is recommended. Face the bottle mouth upstream by swinging the sampling device downstream and then allow it to drop into the water, without slack in the rope. Pull the sample device rapidly upstream and out of the water simulating (imitating) the scooping motion of the hand-sampling described previously. Take care not to dislodge dirt or other debris that might fall into the open sample container from above. Be sure to label the container when sampling is completed.

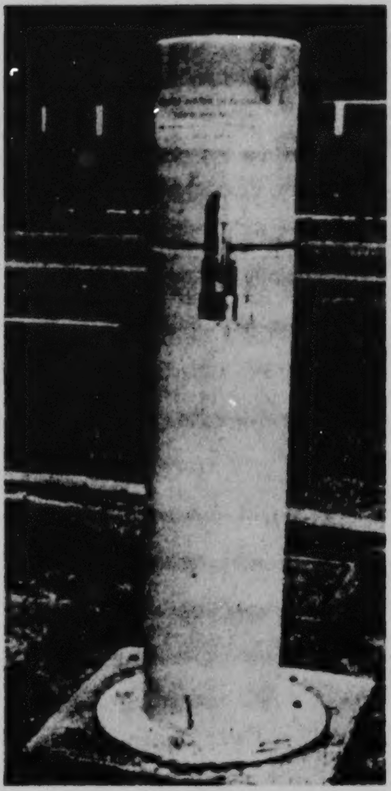


Fig. 11.6 Sampling station

11.241 Depth Sampling

Several additional pieces of equipment are needed for collection of depth samples from basins, tanks, lakes, and reservoirs. These depth samplers require lowering the sample device and container to the desired water depth, then operating, filling, and closing the container and returning the device to the surface. Although depth measurements are best made with a pre-marked steel cable, the sample depths can be determined by pre-measuring and marking a nylon rope at intervals with a non-smearing ink, paint, or finger-nail

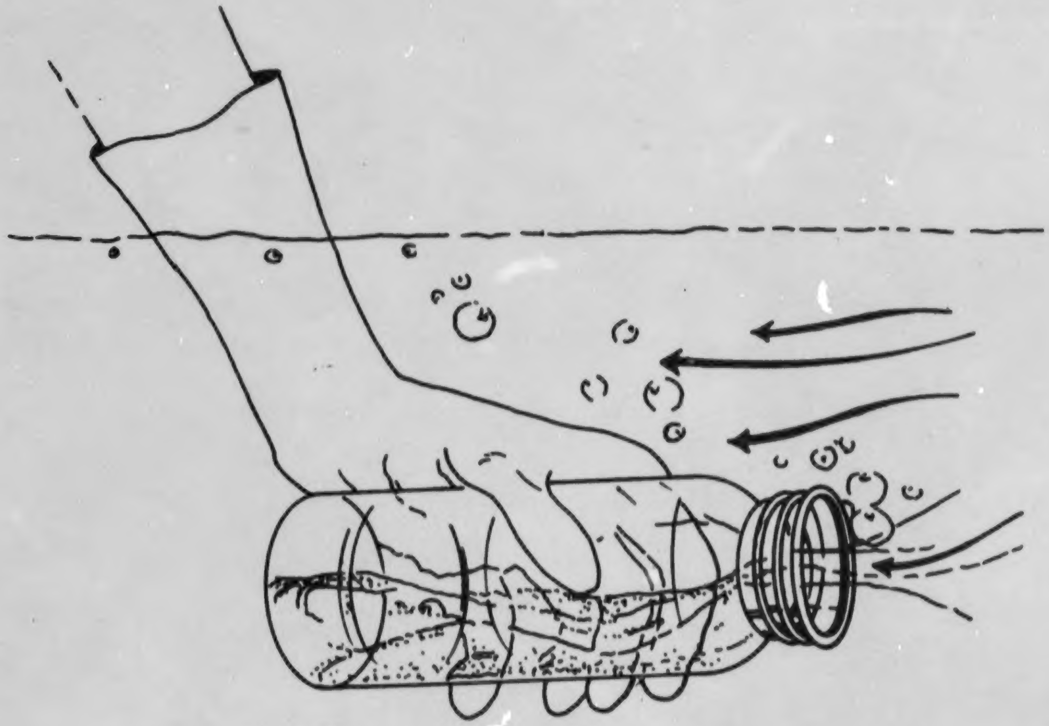


Fig. 11.7 Demonstration of technique used in grab sampling of surface waters

(Source: U.S. EPA, "Microbiological Methods for Monitoring the Environment," Dec. 1978.)

polish. One of the most common commercial devices is called a Kemmerer Sampler (see Figure 11.8). This type of depth sampler consists of a cylindrical tube that contains a rubber stopper or valve at each end. The device is lowered into the water in the open position and the water sample is trapped in the cylinder when the valves are closed by the dropped messenger.

Figures 11.5 and 11.9 show typical depth samplers. These samplers are lowered to the desired depth. A jerk on the cord will remove the stopper and allow the bottle in the depth sampler to fill. Good samples can be collected in depths of water up to 40 feet (12 m).

11.242 Water Tap Sampling

To collect samples from water main connections, first flush the service line for a brief period of time. Samples should not be taken from drinking fountains, restrooms, or taps that have aerators. Aerators can change water quality indicators such as pH and dissolved oxygen, and can harbor bacteria under some conditions. Do not sample from taps surrounded by excessive foliage (leaves, flowers) or taps that are dirty, corroded, or are leaking. Never collect a sample from a hose or any other attachment fastened to a faucet. Care must be taken to be sure that the sample collector does not come in contact with the faucet.

11.25 Sampling Containers and Preservation of Samples

The shorter the time that elapses between the actual collection of the sample and the analysis, the more reliable your results will be. Some tests, such as residual chlorine and temperature, require immediate analysis, while others can be transported to the laboratory. A summary of acceptable sample containers, preservative, and maximum time between sampling and analysis is shown on Table 11.2.

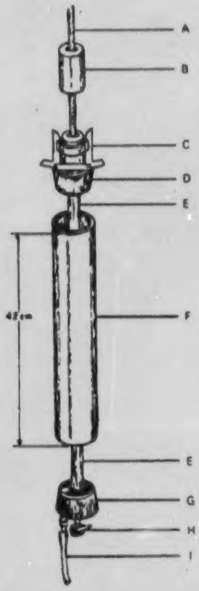


Fig. 11.8 Kemmerer Depth Sampler. (A) nylon line, (B) messenger, (C) catch set so that the sampler is open, (D) top rubber valve, (E) connecting rod between the valves, (F) tube body, (G) bottom rubber valve, (H) knot at the bottom of the suspension line and (I) rubber tubing attached to the spring-loaded check valve.

Source: U.S. EPA "Microbiological Methods for Monitoring the Environment," December 1978.

TABLE 11.2 RECOMMENDATION FOR SAMPLING AND PRESERVATION OF SAMPLES ACCORDING TO MEASUREMENT[a]

Measurement	Vol. Req. (mL)	Container[b]	Preservative	Maximum Holding Time[c]
PHYSICAL PROPERTIES				
Color	50	P,G	Cool, 4°C	48 hours
Conductance	100	P,G	Cool, 4°C	28 days
Hardness[d]	100	P,G	Cool, 4°C HNO_3 to pH <2	6 months
Odor	200	G only	Cool, 4°C	24 hours
pH[d]	25	P,G	Det. on site	2 hours
Residue, Filterable	100	P,G	Cool, 4°C	14 days
Temperature	1000	P,G	Det. on site	Immediately
Turbidity	100	P,G	Cool, 4°C	48 hours
METALS (Fe, Mn)				
Dissolved	200	P,G	Filter on site HNO_3 to pH <2	6 months
Suspended	200		Filter on site	6 months
Total	100	P,G	HNO_3 to pH <2	6 months
INORGANICS, NON-METALLICS				
Acidity	100	P,G	Cool, 4°C	14 days
Alkalinity	100	P,G	Cool, 4°C	14 days
Bromide	100	P,G	None Req.	28 days
Chloride	50	P,G	None Req.	28 days
Chlorine	200	P,G	Det. on site	2 hours
Cyanide	500	P,G	Cool, 4°C NaOH to pH 12	14 days
Fluoride	300	P,G	None Req.	28 days
Iodide	100	P,G	Cool, 4°C	24 hours
Nitrogen				
Ammonia	400	P,G	Cool, 4°C H_2SO_4 to pH <2	28 days
Kjeldahl, Total	500	P,G	Cool, 4°C H_2SO_4 to pH <2	28 days
Nitrate plus Nitrite	100	P,G	Cool, 4°C H_2SO_4 to pH <2	28 days
Nitrate	100	P,G	Cool, 4°C	48 hours
Nitrite	50	P,G	Cool, 4°C	48 hours
Dissolved Oxygen				
Probe	300	G only	Det. on site	1 hour
Winkler	300	G only	Fix on site	8 hours
Phosphorus				
Ortho-phosphate, Dissolved	50	P,G	Filter on site Cool, 4°C	24 hours
Hydrolyzable	50	P,G	Cool, 4°C H_2SO_4 to pH <2	24 hours
Total	50	P,G	Cool, 4°C H_2SO_4 to pH <2	28 days
Total, Dissolved	50	P,G	Filter on site Cool, 4°C H_2SO_4 to pH <2	24 hours
Silica	50	P only	Cool, 4°C	28 days
Sulfate	50	P,G	Cool, 4°C	28 days
Sulfide	500	P,G	Cool, 4°C 2 mL zinc acetate	28 days
Sulfite	50	P,G	Cool, 4°C	48 hours

---

[a] "Guidelines Establishing Test Procedures for the Analysis of Pollutants;" Proposed Regulations; Correction, by U.S. Environmental Protection Agency, Federal Register, Part IV, Vol. 44, No. 244, Tuesday, December 18, 1979, Proposed Rules, pages 75028-75052.

[b] Polyethylene (P) or Glass (G). For metals, polyethylene with a polypropylene cap (no liner) is preferred.

[c] Holding times listed above are recommended for properly preserved samples based on currently available data. It is recognized that for some sample types, extension of these times may be possible while for other types, these times may be too long. Where shipping regulations prevent the use of the proper preservation technique or the holding time is exceeded, such as the case of a 24-hour composite, the final reported data for these samples should indicate the specific variance.

[d] Hardness and pH are usually considered chemical properties of water rather than physical properties.

SPECIAL NOTE

Whenever you collect a sample for a bacteriological test (coliforms), be sure to use a sterile plastic or glass bottle. If the sample contains any chlorine residual, sufficient sodium thiosulfate should be added to neutralize all of the chlorine residual. Usually two drops (0.1 mL) of ten percent sodium thiosulfate for every 100 mL of sample is sufficient, unless you are disinfecting mains or storage tanks.

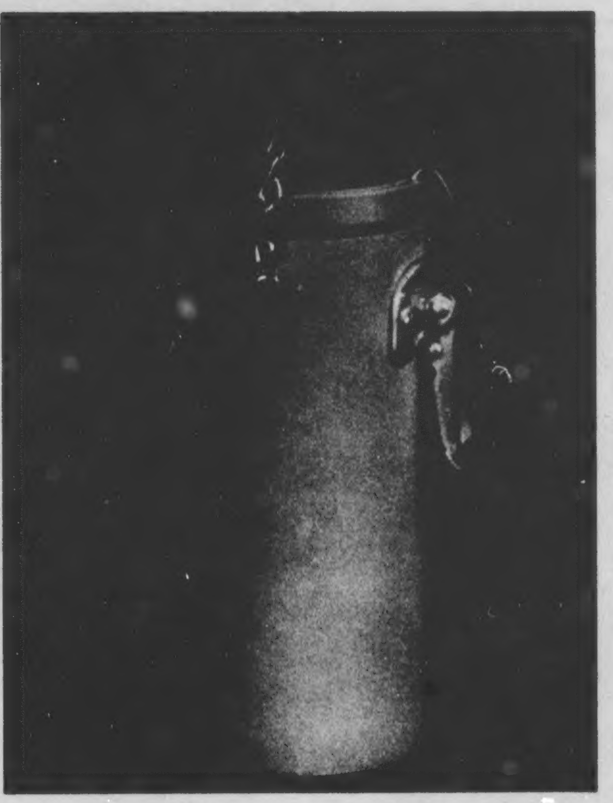


Fig. 11.9 Depth sampler
(Permission of HACH Company)

Whatever types of container you use, clearly identify the sample location, date and time of collection, name of collector, and any other pertinent information.

11.26 Additional Reading

1. See page 35, *STANDARD METHODS*, 15th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 522.

11.2D What are the two general types of samples collected by water treatment personnel?

11.2E List three water quality indicators that are usually measured with a grab sample.

11.2F How would you collect a depth sample from a lake?

11.2G Samples should not be collected from water taps under what conditions?

11.2H What information should be recorded when a sample is collected?

End of Lesson 2 of 5 Lessons
on
LABORATORY
PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. LABORATORY PROCEDURES

(Lesson 2 of 5 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 1.

8. Why are proper sampling procedures important?
9. What is meant by a representative sample?
10. How would you obtain a representative sample?
11. Under what conditions and why would you preserve a sample?

CHAPTER 11. LABORATORY PROCEDURES

(Lesson 3 of 5 Lessons)

11.3 WATER LABORATORY TESTS

1. Alkalinity

A. Discussion

The alkalinity of a water sample is a measure of the water's capacity to neutralize acids. In natural and treated waters, alkalinity is the result of bicarbonates, carbonates, and hydroxides of the metals of calcium, magnesium, and sodium.

Many of the chemicals used in water treatment, such as alum, chlorine, or lime, cause changes in alkalinity. The alkalinity determination is a useful tool in calculating chemical dosages needed in coagulation and water softening. Alkalinity must also be known to calculate corrosivity and to estimate the carbonate hardness of water. Alkalinity is usually expressed in terms of *CALCIUM CARBONATE* $(CaCO_3)$.[5]

There are five alkalinity conditions possible in a water sample: (1) bicarbonate alone, (2) bicarbonate and carbonate, (3) carbonate alone, (4) carbonate and hydroxide, and (5) hydroxide alone. These five conditions may be distinguished and quantities determined from the results of acid titrations by the method given below.

B. What is Tested

Sample	Common Range, mg/*L*
Raw and Treated Surface Water	20 - 300
Well Water	80 - 500

C. Apparatus Required

pH meter
reference electrode
glass electrode
magnetic stirrer
magnetic stir-bar
analytical balance
graduated cylinder (100 m*L*)
buret (25 m*L*)
buret support
beaker (250 m*L*)
wash bottle
desiccator

D. Reagents

(*NOTE:* Standardized solutions are commercially available for most reagents. Refer to *STANDARD METHODS* if you wish to prepare your own reagents.)

1. Sodium carbonate (Na_2CO_3) solution, approximately 0.05 *N.*
2. Sulfuric acid (H_2SO_4), 0.1 *N.*
3. Standard sulfuric acid, 0.02 *N*: Dilute 200 m*L* 0.10 *N* standard acid to 1 liter using a volumetric flask. To determine the volume to be diluted, use the following formula:

$$\text{Volume diluted, m}L = \frac{(\text{Standard, } 0.02\ N) \times (1000\ \text{m}L)}{(\text{Calculated Normality, } 0.10\ N)}$$

$$= \frac{(0.02\ N) \times (1000\ \text{m}L)}{(0.10\ N)}$$

$$= 200\ \text{m}L$$

E. Procedure

Total and Phenolphthalein Alkalinity

1. Take a clean beaker and add 100 m*L* of sample (or other sample volume that will give a titration volume of less than 50 m*L* of acid titrant).
2. Place electrodes of pH meter into beaker containing sample.
3. Stir sample slowly (with a magnetic stirrer if possible).
4. Check pH of sample. If pH is 8.3 or below, then there is no phenolphthalein alkalinity present and you can go to step 6.
5. If the pH is greater than 8.3, titrate very carefully to a pH of 8.3 with 0.02 *N* H_2SO_4. Record the amount of acid used to this point.
6. Continue to titrate to pH 4.5 with 0.02 *N* 0.02 *N* H_2SO_4.[6] Record the total amount of acid used from starting point to finish.
7. Calculate Total and Phenolphthalein (if present) Alkalinities.

F. Example

Results from alkalinity titrations on a finished water sample were as follows:

Sample size=100 m*L*
m*L* titrant used to pH 8.3, A=0.5 m*L*
total m*L* of titrant used, B=6.8 m*L*
Acid Normality, N=0.02 *N* H_2SO_4

G. Calculations

Phenolphthalein Alkalinity, m*L* as $CaCO_3$

$$= \frac{A \times N \times 50{,}000}{\text{m}L\text{ of sample}}$$

$$= \frac{(0.5\ \text{m}L) \times (0.02\ N) \times 50{,}000}{100\ \text{m}L}$$

$$= 5\ \text{mg}/L$$

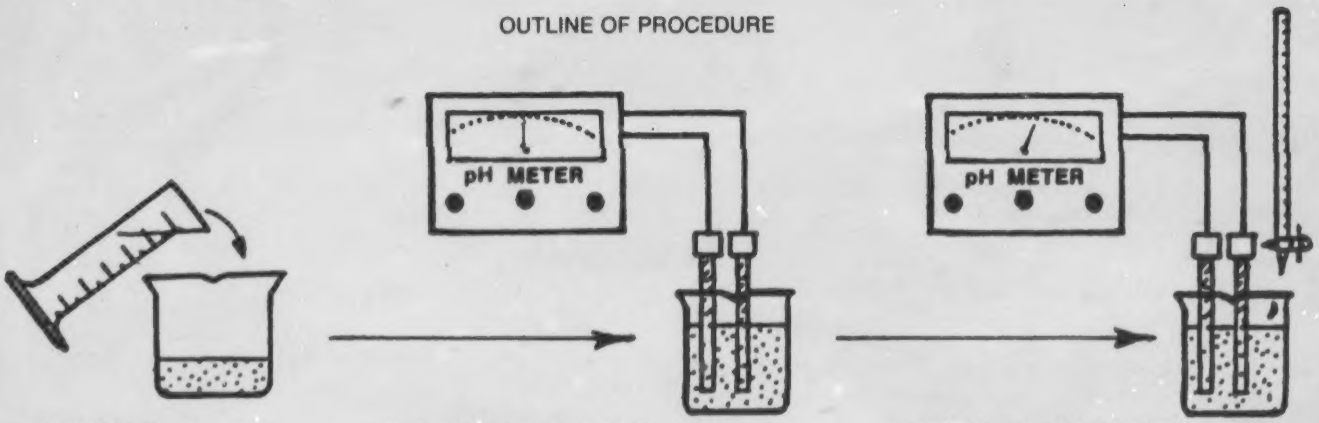
---

[5] *Calcium Carbonate* $(CaCO_3)$ *Equivalent. An expression of the concentration of specific constituents in water in terms of their equivalence to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.*

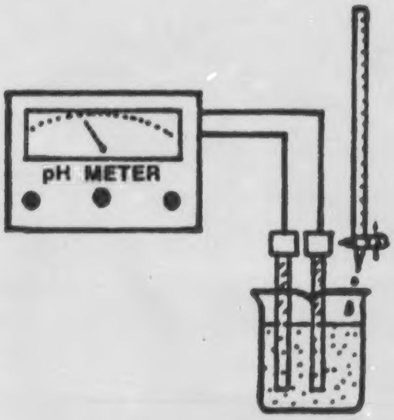
[6] *STANDARD METHODS, 15th Edition, page 254, recommends titrating to a pH of 4.5 for routine or automated analyses. However, other pH levels are suggested for various levels of alkalinity.*

(Alkalinity)

OUTLINE OF PROCEDURE



1. Add 100 m*L* of sample.
2. Place electrodes* of pH meter in beaker.
3. Titrate down to pH 8.3 (if necessary), with 0.02 *N* H_2SO_4.



4. Continued to titrate to pH 4.5.

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* Some pH meters have a single "combination" electrode.

Total Alkalinity, mg/*L* as $CaCO_3$

$$= \frac{B \times N \times 50{,}000}{mL \text{ of sample}}$$

$$= \frac{(6.8\ mL) \times (0.02\ N) \times 50{,}000}{100\ mL}$$

$$= 68\ mg/L$$

H. Interpretation of Results

From the test results and the information given below, the different types of alkalinity contained in a water sample can be determined.

Titration Result	Alkalinity, mg/*L* as $CaCO_3$		
	Bicarbonate	Carbonate	Hydroxide
P = 0	T	0	0
P is less than ½ T	T - 2P	2P	0
P = ½ T	0	2P	0
P is greater than ½ T	0	2T - 2P	2P - T
P = T	0	0	T

where P=phenolphthalein alkalinity
T =total alkalinity

Example: The example in "F" above gave the following results:

phenolphthalein alkalinity = 5 mg/*L*
total alkalinity =68 mg/*L*

Since the phenolphthalein alkalinity (5 mg/*L*) is less than one half of the total alkalinity (68 mg/*L*) from the table, then there is bicarbonate and carbonate alkalinity in the water.

The bicarbonate alkalinity in this case is equal to T − 2P or 68 mg/*L* − (2 × 5 mg/*L*) = 58 mg/*L* as $CaCO_3$.

The carbonate alkalinity is equal to 2P or 2 × 5 mg/*L* = 10 mg/*L* as $CaCO_3$.

I. Precautions

1. The sample should be analyzed as soon as possible, at least within a few hours after collection.
2. The sample should not be agitated, warmed, filtered, diluted, concentrated, or altered in any way.

J. Reference

1. See page 253, *STANDARD METHODS*, 15th Edition.
2. See page 310-1-1 *METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES*, March 1979.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on pages 522-523.

11.3A What chemicals used in water treatment will cause changes in alkalinity?

11.3B Why is it important to know the alkalinity of a water sample?

2. Chlorine Residual

A. Discussion

Chlorine is not only an excellent disinfectant but also serves to react with iron, manganese, protein substances, sulfide, and many taste- and odor-producing compounds to help improve the quality of treated water. In addition, chlorine helps to control microorganisms that might interfere with coagulation and flocculation, keeps filter media free of slime growths, and helps bleach out undesirable color.

There are two general types of residual chlorine produced in chlorinated water. They are (1) free residual chlorine and (2) combined residual chlorine. Free residual chlorine refers to chlorine (Cl_2), hypochlorus acid (HOCl), and the hypochlorite ion (OCl^-). Combined residual chlorine generally refers to the chlorine-ammonia compounds of monochloramine (NH_2Cl), dichloramine ($NHCl_2$), and trichloramine (NCl_3 or nitrogen trichloride). Both types of residuals act as disinfectants, but differ in their capacity to produce a germ-free water supply during the same contact time.

In addition to all the positive aspects of chlorination, there may be some adverse effects. Potentially carcinogenic chlororganic compounds such as chloroform and other THMs may be formed during the chlorination process. To minimize any adverse effects, the operator should be familiar with the concentrations of free and combined residual chlorine produced in a water supply following chlorination. Both residuals are extremely important in producing a potable water that is not only safe to drink but is also free of objectionable tastes and odors.

B. What is Tested

Source	Common Range Residual Chlorine, mg/*L* Free	Total
Chlorinated Raw Surface Water (Pre-Chlorination)	0.3 to 3	0.5 to 5
Chlorinated Finished Surface Water (Post-Chlorination)	0.2 to 1	0.3 to 1.5
Well Water	0.2 to 1	0.2 to 1

C. Methods

There are seven methods listed for measuring residual chlorine in the 15th Edition of *STANDARD METHODS*. Selection of the most practical and appropriate procedure in any particular instance generally depends upon the characteristics of the water being examined. The *AMPEROMETRIC*[7] titration method is a standard of comparison for determining free or combined chlorine residual. This method is relatively free of interferences but does require greater operator skill to obtain good results. In addition, the titration instrument is expensive.

The DPD[8] methods are simpler to perform than amperometric titration but are subject to interferences due to manganese. Field comparator kits are available from several suppliers such as Hellige, Wallace & Tiernan, and Hach.

D. Apparatus Required

1. Amperometric Titration Method

   See page 286, *STANDARD METHODS*, 15th Edition and amperometric titrator's instruction manual.

2. DPD Colorimetric Method (Field Comparator Kit)

   Field Comparator
   Sample cells

3. DPD Titrimetric Method[9]

   Graduated cylinder (100 m*L*)
   Pipets (1 and 10 m*L*)
   Flask, Erlenmeyer (250 m*L*)
   Buret (10 m*L*)
   Magnetic Stirrer
   Magnetic stir-bar
   Balance, analytical

Fragile Handle with Care

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[7] *Amperometric (am-PURR-o-MET-rick). A method of measurement that records electric current flowing or generated, rather than recording voltage. Amperometric titration is a means of measuring concentrations of certain substances in water.*

[8] *DPD. A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with standards. DPD stands for N, N-diethyl-p-phenylene-diamine.*

[9] *Some regulatory agencies require the use of the DPD Titrimetric Method if chlorine residual testing is used in place of some of the coliform tests.*

(Chlorine Residual)

E. Reagents

(*NOTE:* Prepared reagents may be purchased from laboratory chemical supply houses.)

Amperometric Titration Method

1. Standard phenylarsine oxide (PAO) solution, 0.00564 *N* *CAUTION:* Toxic — avoid ingestion.
2. Acetate buffer solution, pH 4.
3. Phosphate buffer solution, pH 7.
4. Potassium iodide solution.

   Store in brown glass-stoppered bottle, preferably in the refrigerator. Discard when solution becomes yellow.

DPD Colorimetric Method (Field Comparator Kit)

Use reagents supplied by kit manufacturer.

DPD Titrimetric Method

1. 1 + 3 H_2SO_4. *CAREFULLY* add 10 m*L* concentrated sulfuric acid to 30 m*L* distilled water. Cool.
2. Phosphate Buffer Solution.
3. DPD Indicator Solution.
4. Standard Ferrous Ammonium Sulfate (FAS) Titrant, 0.00282 *N*.
5. Potassium iodide, KI, crystals.

F. Procedure

Amperometric Titration Method

Follow manufacturer's instructions.

DPD Colorimetric Method (Field Comparator Kit)

To measure chlorine residuals you should follow the directions provided by the manufacturer of the equipment or instrument you are using.

If you are disinfecting clear wells, distribution reservoirs or mains and very high chlorine residuals must be measured, a drop-dilution technique can be used to estimate the chlorine residual. The procedure is as follows:

1. Add 10 m*L* of distilled water and one powder pillow of DPD reagent (or 0.5 m*L* of DPD solution) to the sample tube of the test kit.
2. Add a sample of the water being tested on a drop-by-drop basis to the sample tube until a color is produced.
3. Record the number of drops added to the sample tube. Assume one drop equals 0.05 m*L*.
4. Determine the chlorine residual in the sample as a result of the color produced and record the residual in milligrams per liter.

EXAMPLE 3

The recorded chlorine residual is 0.3 mg/*L*. Two drops of sample produced a chlorine residual of 0.3 mg/*L* in 10 m*L* of distilled water. Assume 0.05 m*L* per drop.

Known		**Unknown**
Chlorine Residual, mg/*L*	= 0.3 mg/*L*	Actual Chlorine Residual, mg/*L*
Sample Volume, drops	= 2 drops	
Distilled Water, m*L*	= 10 m*L*	

Calculate the actual residual in milligrams per liter.

$$\text{Actual Chlorine Residual, mg}/L = \frac{(\text{Chlorine Residual, mg}/L)(\text{Distilled Water, m}L)}{(\text{Sample Volume, drops})(0.05\ \text{m}L/\text{drop})}$$

$$= \frac{(0.3\ \text{mg}/L)(10\ \text{m}L)}{(2\ \text{drops})(0.05\ \text{m}L/\text{drop})}$$

$$= 30\ \text{mg}/L$$

DPD Titrimetric Method

FOR FREE RESIDUAL CHLORINE

1. Place 5 m*L* each of buffer reagent and DPD indicator in a 250 m*L* flask and mix.
2. Add 100 m*L* of sample and mix.
3. Titrate rapidly with standard FAS titrant until red color is discharged (disappears).
4. Record amount of FAS used (Reading A). If combined residual chlorine fractions are desired, continue to next step.

FOR COMBINED RESIDUAL CHLORINE

Monochloramine

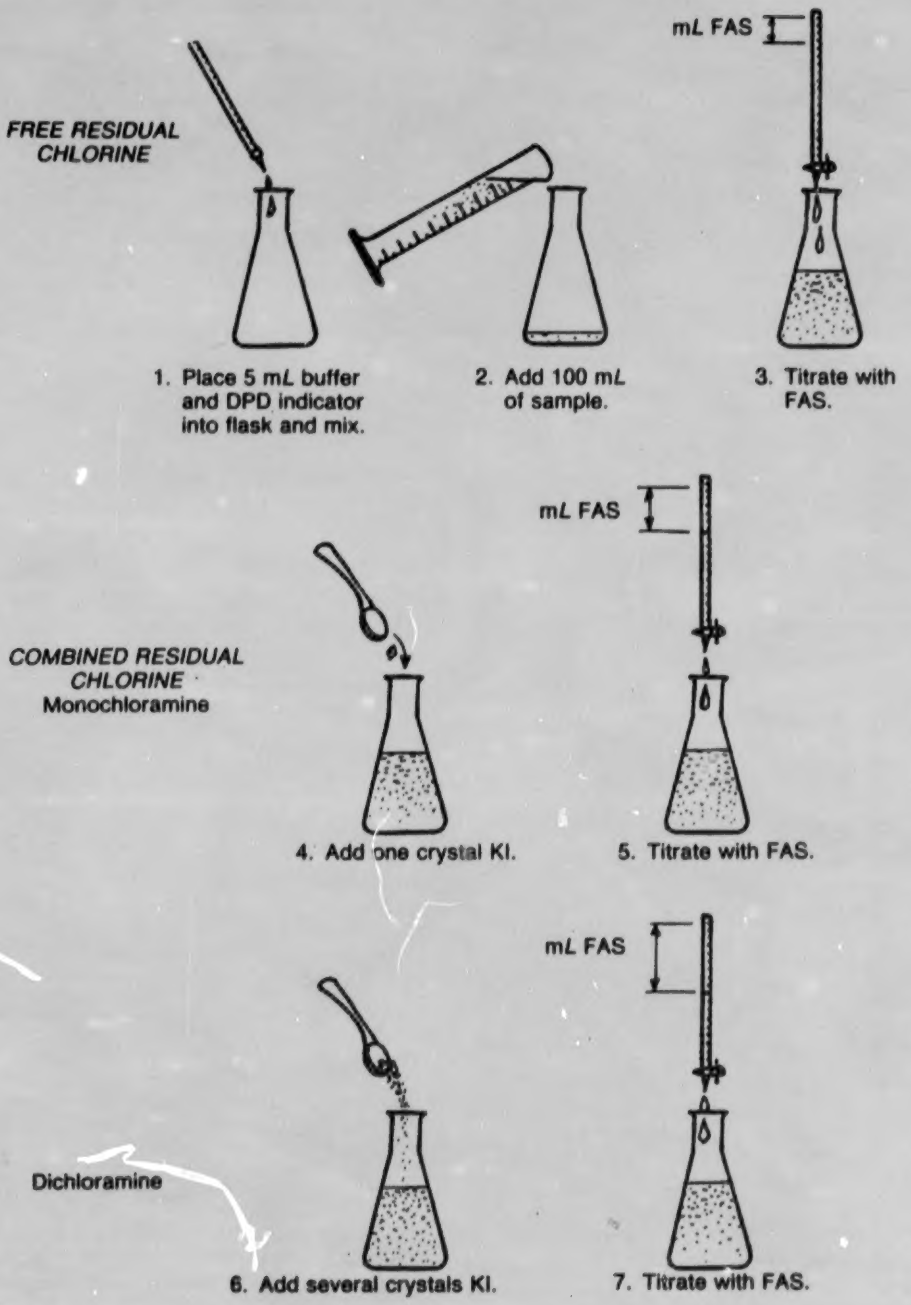
5. Add one very small crystal of KI and mix. If monochloramine is present, the red color will re-appear.
6. Continue titrating carefully until red color again disappears.
7. Record reading of FAS in the buret used to this point (this includes amount used above). This is Reading B.

Dichloramine

8. Add several crystals KI (about 1 g) and mix until dissolved.
9. Let stand 2 minutes.
10. Continue amount of FAS used to this point. This includes amounts used in two previous titrations for free and monochloramine. This is reading C.

NOTE: Manufacturers of laboratory equipment are continually developing faster and more accurate ways to measure chlorine residual. If you have new equipment, follow the manufacturer's procedures.

OUTLINE OF PROCEDURE


FREE RESIDUAL CHLORINE
mL FAS
1. Place 5 mL buffer and DPD indicator into flask and mix.
2. Add 100 mL of sample.
3. Titrate with FAS.
COMBINED RESIDUAL CHLORINE
Monochloramine
mL FAS
4. Add one crystal KI.
5. Titrate with FAS.
Dichloramine
mL FAS
6. Add several crystals KI.
7. Titrate with FAS.

G. Precautions

1. For accurate results, careful pH control is essential.

   The pH of the sample, buffer, and DPD indicator together should be between 6.2 and 6.5.

2. If the sample contains oxidized manganese, an inhibitor must be used.

3. Samples should be analyzed as soon as possible after collection.

4. If nitrogen trichloride or chlorine dioxide are present, special procedures are necessary.

H. Example

A sample taken after prechlorination at a filtration plant was tested for residual chlorine using the DPD Titrimetric Method.

mL of sample = 100 mL
Reading A, mL = 1.4 mL
Reading B, mL = 1.6 mL
Reading C, mL = 2.7 mL

I. Calculation

READING	*CHLORINE RESIDUAL*
A	= mg/L free residual chlorine
B-A	= mg/L monochloramine
C-B	= mg/L dichloramine
C-A	= mg/L combined available chlorine
C	= mg/L total residual chlorine

Example: The concentrations of the different types of residual chlorine present can be calculated from the information given in (H).

READING	*CHLORINE RESIDUAL*
A = 1.4 mL	= 1.4 mg/L free residual chlorine
B-A = 1.6-1.4	= 0.2 mg/L monochloramine
C-B = 2.7-1.6	= 1.1 mg/L dichloramine
C-A = 2.7-1.4	= 1.3 mg/L combined available chlorine
C = 2.7 mL	= 2.7 mg/L total residual chlorine

J. Interpretation of Results

1. Any "chlorine" taste and odor that may result from chlorination would generally be from the dichloramine or nitrogen trichloride nuisance residuals.

2. Free residual chlorination produces the best results when the free residual makes up more than 80 percent of the total residual. However, this will not be the case if ammonia is added to the water being treated to form chloramines in order to prevent the formation of THMs.

K. Reference

See page 277, *STANDARD METHODS*, 15th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3C List some of the important benefits of chlorinating water.

11.3D What is a potential adverse effect from chlorination?

3. Chlorine Demand

A. Discussion

The chlorine demand of water is the difference between the amount of chlorine applied (or dosed) and the amount of free, combined, or total residual chlorine remaining at the end of a specific contact period. The chlorine demand varies with the amount of chlorine applied, time of contact, pH and temperature. Also the presence of organics and reducing agents in water will influence the chlorine demand. The chlorine demand test should be conducted with chlorine gas or with granular hypochlorite, depending upon which form you usually use for chlorination.

The chlorine demand test can be used by the operator to determine the best chlorine dosage to achieve specific chlorination objectives. The measurement of chlorine demand is performed by treating a series of water samples in question with known but varying amounts of chlorine or hypochlorite. After the desired contact time, calculation of residual chlorine in the samples will demonstrate which dosage satisfied the requirements of the chlorine demand in terms of the residual desired.

B. What is Tested

	Common Range Chlorine Demand, mg/L
Surface	0.5 to 5
Well Water	0.1 to 1.3

C. Apparatus

In addition to the apparatus described under one of the methods for chlorine residual, the following items are required:

Flasks, Erlenmeyer (1000 mL)
Pipets (5 and 10 mL)
Graduated cylinder (500 mL)
Flask, volumetric (1000 mL)
Flask, Erlenmeyer (250 mL)
Buret (25 mL)

D. Reagents

In addition to the reagents described under the method you will use to determine chlorine residual, the following items are also needed:

1. Stock chlorine solution. Obtain a suitable solution from a chlorinator solution line or by purchasing a bottle of household bleach ("Chlorox" or similar product). Store in a dark, cool place to maintain chemical strength. Household bleach products usually contain approximately five percent available chlorine which is about 50,000 mg/L.

2. Chlorine dosing solution. If using household bleach, carefully pipet about 10 mL of the bleach into a 1000 mL volumetric flask. Fill to the mark with chlorine demand-free water and standardize. If using a stock chlorine solution obtained from a chlorinator solution line, simply standardize this solution directly.

   Standardization:

   a. Place 2 mL acetic acid and 20 mL chlorine demand-free water in a 250 mL flask.

   b. Add about 1 g KI crystals.

c. Measure into the flask a suitable volume of chlorine dosing solution. If using household bleach as your stock solution, add 25 mL of the dosing solution. Note: In measuring the volume of the dosing solution, notice that 1 mL of the 0.025 N thiosulfate titrant is equal to 0.9 mg chlorine.

d. Titrate with standardized 0.025 N thiosulfate titrant until the yellow iodine color almost disappears.

e. Add 1 to 2 mL starch indicator solution.

f. Continue to titrate until blue color disappears.

$$\text{mg/}L\text{ Cl as Cl}_2/\text{m}L = \frac{(\text{m}L\text{ thiosulfate used}) \times N \times 35.45}{\text{m}L\text{ of dosing solution}}$$

where N = normality of thiosulfate titrant

3. Acetic acid, concentrated (glacial).
4. Potassium Iodide, KI, crystals.
5. Standard sodium thiosulfate 0.025 N.
6. Chlorine-demand-free water. Prepare chlorine-demand-free water from good quality distilled or deionized water by adding sufficient chlorine to give 5 mg/L free chlorine residual. After standing 2 days, this solution should contain at least 2 mg/L free residual chlorine. If not, discard and obtain better quality water. Remove remaining free chlorine by placing the solution in the direct sunlight. After several hours, measure total chlorine residual. Do not use until last trace of chlorine has been removed.
7. Starch indicator.

E. Procedure

1. Measure a 500 mL sample into each of five to ten 1000 mL flasks or bottles.
2. To the first flask, add an amount of chlorine that leaves no residual at the end of the contact time. Mix.
3. Add increasing amounts of chlorine to successive portions of the sample and mix.
4. Measure residual chlorine after the specific contact time. Record results.
5. On graph paper, plot the residual chlorine (or the amount of chlorine consumed) versus chlorine dosage.

F. Precautions

1. Dose sample portions at time intervals that will leave you enough time for chlorine residual testing at predetermined contact times.
2. Conduct test over the desired contact time. If test objective is to duplicate your plant contact time, then match plant detention time as closely as possible.
3. Keep samples in the dark, protected from sunlight.
4. Temperature should be kept as constant as possible.
5. If test has bacteriologic objective, all glassware must be sterilized.

G. Example

A raw water sample was collected from a river to determine chlorine demand.

Contact time=30 minutes (plant detention time)
pH=7.6
Temperature=15°C

Results from the chlorine demand test were as follows:

Flask No.	Chlorine Added, mg/L	Free Residual Chlorine after 30 min, mg/L
1	0.5	0.36
2	1.0	0.82
3	1.5	1.14
4	2.0	0.60
5	2.5	0.75
6	3.0	1.25

H. Calculation

Calculate the chlorine demand by using the formula

$$\underset{\text{mg/}L}{\text{Chlorine Demand,}} = \underset{\text{mg/}L}{\text{Chlorine Added,}} - \underset{\text{mg/}L}{\text{Free Residual Chlorine,}}$$

Flask No.	Chlorine Added, mg/L	−	Free Residual Chlorine, mg/L	=	Chlorine Demand, mg/L
1	0.5	−	0.36	=	0.14
2	1.0	−	0.82	=	0.18
3	1.5	−	1.14	=	0.36
4	2.0	−	0.60	=	1.40
5	2.5	−	0.75	=	1.75
6	3.0	−	1.25	=	1.75

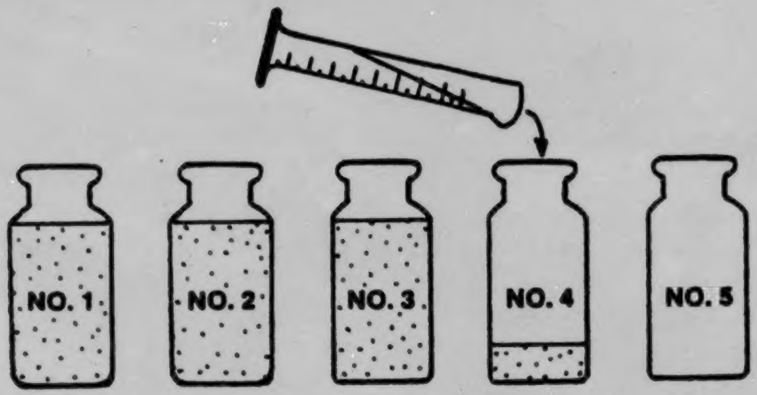
Valuable knowledge can be gained by plotting the data from test results. Figure 11.10 is a plot of the chlorine added vs. the free chlorine residual after 30 minutes. By drawing a smooth line between the plotting points, a typical breakpoint chlorination curve is produced.

Figure 11.11 is a plot of the chlorine demand curve. Note that the far right end of the curve is flat which indicates that the chlorine demand has been satisfied. The curve reveals that the chlorine demand will increase as chlorine is added to water until you have gone past the breakpoint.

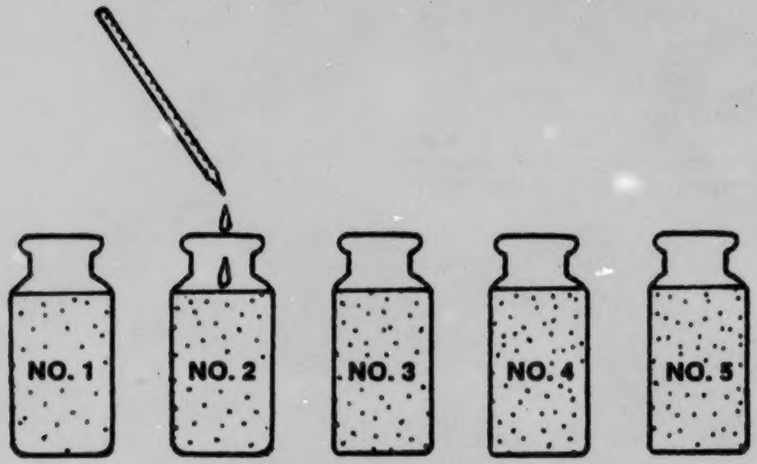
I. Reference

See page 301, *STANDARD METHODS*, 15th Edition.

OUTLINE OF PROCEDURE


NO. 1
NO. 2
NO. 3
NO. 4
NO. 5

1. Measure 500 m*L* water sample to each container.


NO. 1
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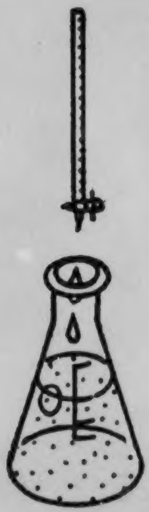
NO. 4
NO. 5

2. Add desired dosage of chlorine to each container.



3. After end of desired contact time, measure chlorine residual. Plot results on graph paper.

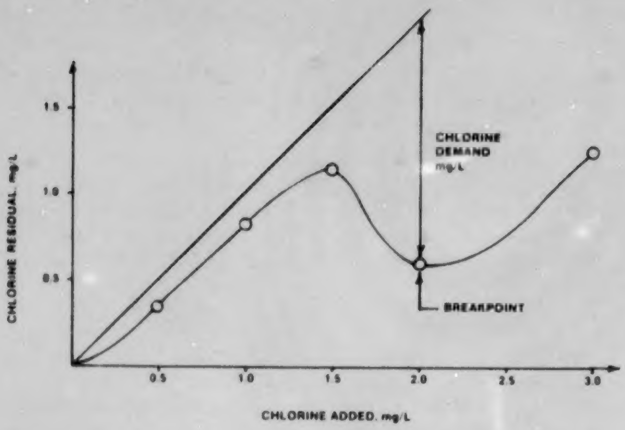


Fig. 11.10 Breakpoint chlorination curve

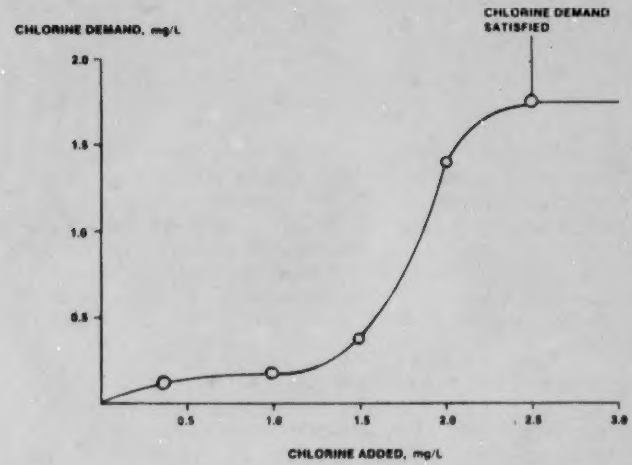


Fig. 11.11 Plot of chlorine demand on graph paper

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3E What conditions can cause variations in the chlorine demand?

11.3F How does the operator use the results from the chlorine demand test?

11.3G Calculate the chlorine demand for a raw water sample if chlorine is added at 2.0 mg/*L* and the free residual chlorine after 30 minutes was 0.4 mg/*L*.

End of Lesson 3 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. LABORATORY PROCEDURES

(Lesson 3 of 5 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 2.

12. What precautions must be taken with the sample when conducting the alkalinity test?
13. What could be the causes of tastes and odors that might result from chlorination?
14. What precautions should be exercised when performing a chlorine demand test?

CHAPTER 11. LABORATORY PROCEDURES

(Lesson 4 of 5 Lessons)

4. Coliform Bacteria

A. Discussion

An improperly treated or unprotected water supply may contain microorganisms that are pathogenic, that is capable of producing disease. Testing for specific pathogenic microorganisms (pathogens which cause diseases such as typhoid or dysentery) is very time-consuming and requires special techniques and equipment. So instead of testing for pathogens, water is generally analyzed for the presence of an "indicator organism," the coliform group of bacteria.

Coliform bacteria, or rather their absence, are a good index of the degree of bacteriologic safety of a water supply. In general, coliform bacteria can be divided into a fecal and a non-fecal group. Fecal coliform bacteria occur normally in the intestines of humans and other warm-blooded animals. They are discharged in great numbers in human and animal wastes. Coliforms are generally more hardy than true pathogenic bacteria and their absence from water is thus a good indication that the water is bacteriologically safe for human consumption. The presence of coliforms, however, indicates the potential presence of pathogenic organisms, that may have entered the water with them, and suggests that the water is not safe to drink.

The coliform group of bacteria includes all the aerobic and *FACULTATIVE*[10] anaerobic gram-negative, nonspore-forming rod-shaped bacteria that ferment lactose (a sugar) within 48 hours at 35°C (human body temperature). The fecal coliform can grow at a higher temperature (45°C) than the non-fecal coliform.

The bacteriological quality of water supplies is subject to control by federal, state, and local agencies, all of which are governed by the rules and regulations contained in the Safe Drinking Water Act. This law stipulates the methods to be used, the number of samples required, and the maximum levels allowed for coliform organisms in drinking water supplies. The number of samples required is generally based on population served by the water system. The maximum contaminant level (MCL) for coliforms is one organism per 100 m*L*. Operators should strive to produce finished water with zero coliforms.

B. Test Methods

Approved water testing procedures for total coliform bacteria are (1) the Multiple Tube Fermentation Method (sometimes called the Most Probable Number or MPN procedure) and (2) the Membrane Filter (MF) Method.

1. Multiple Tube Fermentation Method (MPN)

The multiple tube coliform test has been a standard method for determining the coliform group of bacteria since 1936. In this procedure tubes of lauryl tryptose broth are inoculated with a water sample. Lauryl tryptose broth contains lactose which is the source of carbohydrates (sugar). The coliform density is then calculated from statistical probability formulas that predict the most probable number (MPN) of coliforms in a 100 m*L* sample necessary to produce certain combinations of "gas-positive" (gas forming) and gas-negative tubes in the series of inoculated tubes.

There are three distinct test states for coliform testing using the Multiple Tube Fermentation Method — the Presumptive Test, the Confirmed Test, and the Completed Test. Each test makes the coliform test more valid and specific. These tests are described in detail in the following paragraphs.

2. Membrane Filter (MF) Method

This method was introduced as a tentative method in 1955 and has been an approved test for coliform bacteria since 1960. The basic procedure involves filtering a known volume of water through a membrane filter of optimum pore size for full coliform bacteria retention. As the water passes through the microscopic pores, bacteria are entrapped on the upper surface of the filter. The membrane filter is then placed in contact with either a paper pad saturated with liquid medium or directly over an agar (gelatin-like) medium to provide proper nutrients for bacterial growth. Following incubation under prescribed conditions of time, temperature, and humidity, the cultures are examined for coliform colonies that are counted directly and recorded as a density of coliform per 100 m*L* of water sample.

There are certain important limitations to membrane filter methods. Some types of samples cannot be filtered because of excessive turbidity, high non-coliform bacterial densities, or heavy-metal (bactericidal) compounds. In addition, coliforms contained in chlorinated supplies sometimes do not give characteristic reactions on the media and hence special procedures must then be used.

C. What is Tested

	Common Range Total Coliform per 100 m*L*
Surface waters	50 to 1,000,000
Treated water supplies	0
Well water	0 to 50

D. Materials Required

1. Sampling Bottles

Bottles of glass or other material which are watertight, resistant to the solvent action of water and capable of being sterilized may be used for bacteriologic sampling. Plastic bottles made of nontoxic materials are also satisfactory and eliminate the possibility of breakage during transport. The bottles should hold a sufficient volume of sample for all tests, permit proper washing, and maintain the samples uncontaminated until examinations are complete.

Before sterilization by autoclave, add 0.1 m*L* 10 percent sodium thiosulfate per 4 ounce bottle (120 m*L*). This will neutralize a sample containing about 15 mg/*L* residual chlorine. If the residual chlorine is not neutralized, it would continue to be toxic to the coliform organisms remaining in the sample and give false results.

---

[10] *Facultative (FACK-ul-tay-tive). Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food materials such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.*

When filling bottles with sample, do not flush out sodium thiosulfate or contaminate bottle or sample. Fill bottles approximately three-quarters full and start test in laboratory within six hours. If the samples cannot be processed within one hour, they should be held below 10°C for not longer than six hours.

2. Glassware

All glassware must be thoroughly cleansed using a suitable detergent and hot water (160°F or 71°C), rinsed with hot water (180°F or 82°C) to remove all traces of residual detergent, and finally rinsed with distilled or deionized water.

3. Water

Only distilled water or demineralized water which has been tested and found free from traces of dissolved metals and bactericidal and inhibitory compounds may be used for preparation of culture media.

4. Buffered[11] Dilution Water

Prepare a stock solution by dissolving 34 grams of KH_2PO_4 in 500 m*L* distilled water, adjusting the pH to 7.2 with 1 *N* NaOH and dilute to one liter. Prepare dilution water by adding 1.25 m*L* of the stock solution and 5.0 m*L* magnesium sulfate (50 grams $MgSO_4 \cdot 7\ H_2O$ dissolved in one liter of water) to 1 liter distilled water. This solution can be dispersed into various size dilution blanks or used as a sterile rinse for the membrane filter test.

5. Media Preparation

Careful media preparation is necessary for meaningful bacteriological testing. Attention must be given to the quality, mixing, and sterilization of the ingredients. The purpose of this care is to assure that if the bacteria being tested for are indeed present in the sample, every opportunity is presented for the development and ultimate identification. Much bacteriological identification is done by noting changes in the medium; consequently, the composition of the medium must be standardized. Much of the tedium of media preparation can be avoided by purchase of dehydrated media (Difco, BBL, or equivalent) from local scientific supply houses. The operator is advised to make use of these products; and, if only a limited amount of testing is to be done, consider using tubed, prepared media.

MEDIA — MPN (TOTAL COLIFORM)

a. Lauryl Tryptose Broth

For the Presumptive Coliform Test, dissolve the recommended amount of the dehydrated media in distilled water. Dispense solution into fermentation tubes containing an inverted glass vial (see illustration of the tube with vial on page 504). For 10 m*L* water portions from samples, double-strength media is required while all other inoculations require single strength. Directions for preparation are given on the media bottle label.

b. Brilliant Green Bile Broth

For the Confirmed Coliform Test, dissolve 40 grams of the dehydrated media in one liter of distilled water. Dispense and sterilize as with Lauryl Tryptose Broth.

MEDIA — MEMBRANE FILTER METHOD (TOTAL COLIFORM)

a. M-Endo Broth

Prepare this media by dissolving 48 grams of the dehydrated product in one liter of distilled water which contains 20 m*L* of ethyl alcohol[12] per liter. Heat solution to boiling only — *DO NOT AUTOCLAVE.* Promptly remove solution from heat and cool. Prepared media should be stored in a refrigerator and used within 96 hours.

b. LES Endo Agar

Prepare this media, used for the two-step procedure, as per instructions found on the bottle.

6. Media Storage

Culture media should be prepared in batches of such size that the entire batch will be used in less than one week.

7. Autoclaving

Steam autoclaves are used for the sterilization of the liquid media and associated apparatus. They sterilize (killing of all organisms) at a relatively low temperature of 121°C within 15 minutes by utilizing moist heat.

Components of the media, particularly sugars such as lactose, may decompose at higher temperatures or longer heating times. For this reason adherence to time and temperature schedules is vital. The maximum elapsed time for exposure of the medium to any heat (from the time the autoclave door is closed to unloading) is 45 minutes. Preheating the autoclave can reduce total heating time.

Autoclaves operate in a manner similar to the familiar kitchen pressure cooker:

a. Water is heated in a boiler to produce steam.

b. The steam is vented to drive out air.

c. The steam vent is closed when the air is gone.

---

[11] *Buffer. A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.*

[12] *In some states the ethyl alcohol used in bacteriological media preparation CANNOT be the specially denatured alcohol sold by supply houses to people without an alcohol permit. One way to obtain suitable ethanol under these circumstances is to buy a brand of ethanol sold for human consumption.*

(Coliform)

d. Continued heat raises the pressure to 15 lbs/sq in (103.4 k Pa or 1.05 kg/sq cm); (at this pressure, pure steam has a temperature of 121°C at sea level only).

e. The heat and pressure are maintained for 15 minutes.

f. The heat is turned off.

g. The steam vent is opened to slowly vent steam until atmospheric pressure is reached. (Fast venting will cause the liquids to boil and overflow tubes.)

h. Sterile material is removed to cool.

In autoclaving fermentation tubes, a vacuum is formed in the inner tubes. As the tubes cool, the inner tubes are filled with sterile medium. Capture of gas in this inner tube from the culture of bacteria is the evidence of fermentation and is recorded as a *POSITIVE TEST*.

E. Procedure for Testing Total Coliform Bacteria

Multiple Tube Fermentation Method

1. *GENERAL DISCUSSION*

Coliform bacteria are detected in water by placing portions of a sample of the water in lauryl tryptose broth. Lauryl tryptose broth is a standard bacteriological media containing lactose (milk) sugar in tryptose broth. The coliform bacteria are those which can grow in this media at 35°C temperature and are able to ferment and produce gas from the lactose within 48 hours. Thus, to detect these bacteria the operator need only inspect the fermentation tubes for gas. A schematic of the coliform test procedure is shown in Figure 11.12.

2. *MATERIALS NEEDED*

FOR UNTREATED WATER SAMPLES

a. Fifteen sterile tubes containing 10 m*L* of lauryl tryptose broth are needed for each sample. Use five tubes for each dilution.

b. Dilution tubes or blanks containing 99 m*L* of sterile buffered distilled water.

c. A quantity of 1 m*L* and 10 m*L* serological pipets. The 1 m*L* pipets should be graduated in 0.1 m*L*.

d. Incubator set at 35 ± 0.5°C.

e. Thermometer verified to be accurate by comparison with a National Bureau of Standards (NBS) certified thermometer.

FOR DRINKING WATER SAMPLES

a. Five sterile tubes of 10 m*L* double-strength lauryl tryptose broth are needed if 10 m*L* of sample is added to each tube. Ten m*L* of lauryl tryptose broth is required in all tubes containing one m*L* or less of sample.

b. Sterile 10 m*L* pipe for each sample.

c. Incubator set at 35 ± 0.5°C.

d. Thermometer verified to be accurate by comparison with a National Bureau of Standards (NBS) certified thermometer, or equivalent.

3. Technique for Inoculation of Sample (Figures 11.13 and 11.14)

All inoculations and dilutions of water samples must be accurate and made so that no contaminants from the air, equipment, clothes or fingers reach the sample, either directly or by way of a contaminated pipet. Clean, sterile pipets must be used for each separate sample.

FOR UNTREATED WATER SAMPLES

a. Shake the sample bottle vigorously 20 times before removing sample volumes.

b. Pipet 10 m*L* of sample directly into each of the first five tubes. Each tube must contain 10 m*L* lauryl tryptose broth (double strength).

NOTE: You must realize that the sample volume applied to the first five tubes will depend upon the type of water being tested. The sample volume applied to each tube can vary from 10 m*L* for high quality waters to as low as 0.00001 m*L* (applied as 1 m*L* of a diluted sample) for highly polluted raw water samples.

NOTE: When delivering the sample into the culture medium, deliver sample portions of 1 m*L* or less down into the culture tube near the surface of the medium. *DO NOT* deliver small sample volumes at the top of the tube and allow them to run down inside the tube; too much of the sample will fail to reach the culture medium.

NOTE: Use 10 m*L* pipets for 10 m*L* sample portions, and 1 m*L* pipets for portions of 1 m*L* or less. Handle sterile pipet only near the mouthpiece, and protect the delivery end from external contamination.

c. Pipet 1 m*L* of water sample into each of the next five lauryl tryptose broth (single strength) tubes.

d. Pipet 1/10 m*L* (0.1 m*L*) of water sample into each of the next five lauryl tryptose broth (single strength) tubes. This makes a 0.1 (1 to 10) dilution.

At this point you have 15 tubes inoculated and can place these three sets of tubes in the incubator; however, your sample specimen may show gas production in all fermentation tubes. This means your sample was not diluted enough and you have no usable results.

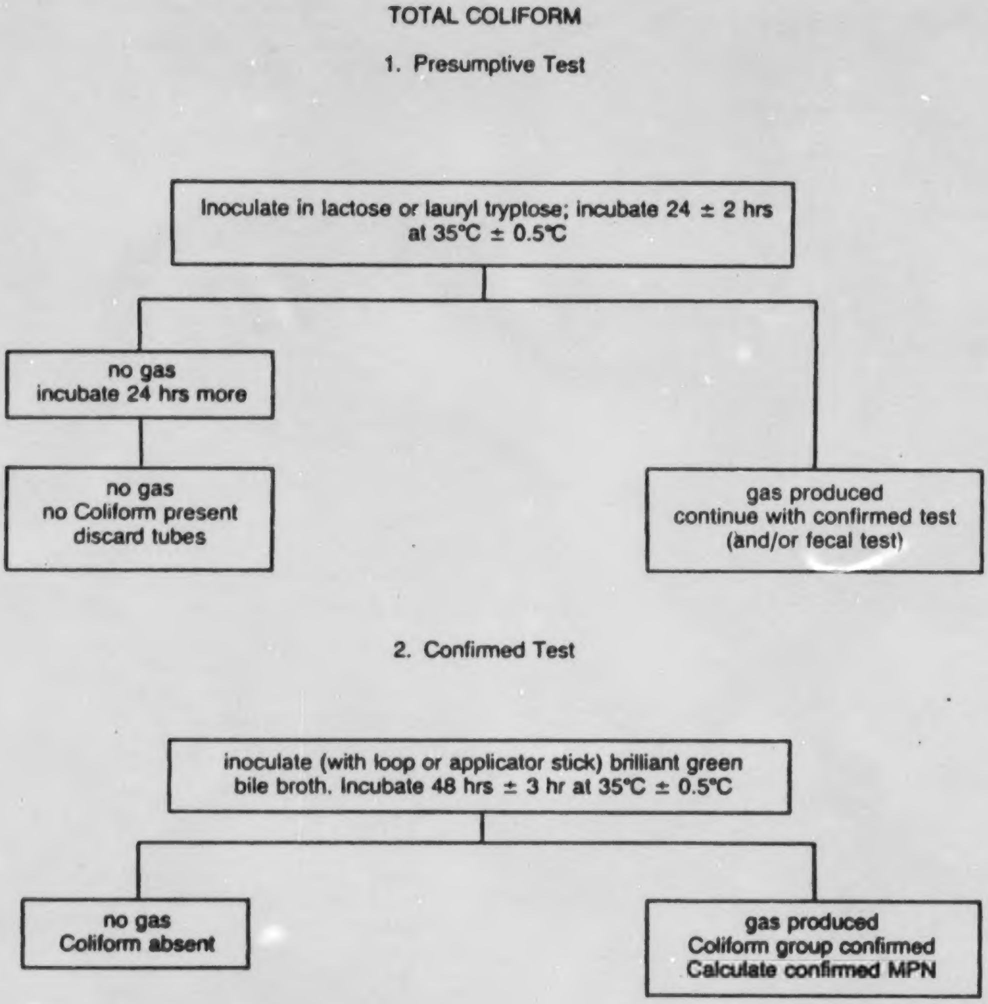

TOTAL COLIFORM
1. Presumptive Test
Inoculate in lactose or lauryl tryptose; incubate 24 ± 2 hrs at 35°C ± 0.5°C
no gas incubate 24 hrs more
no gas no Coliform present discard tubes
gas produced continue with confirmed test (and/or fecal test)
2. Confirmed Test
inoculate (with loop or applicator stick) brilliant green bile broth. Incubate 48 hrs ± 3 hr at 35°C ± 0.5°C
no gas Coliform absent
gas produced Coliform group confirmed Calculate confirmed MPN

Fig. 11.12 Schematic outline of test procedure for Total Coliform — Multiple Tube Fermentation Method

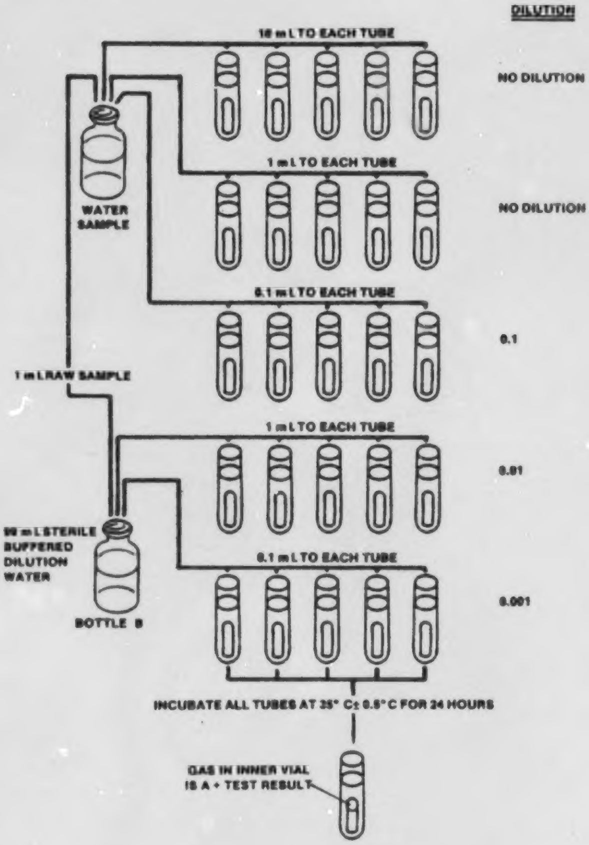

DILUTION
10 mL TO EACH TUBE
NO DILUTION
1 mL TO EACH TUBE
NO DILUTION
WATER SAMPLE
0.1 mL TO EACH TUBE
0.1
1 mL RAW SAMPLE
1 mL TO EACH TUBE
0.01
99 mL STERILE BUFFERED DILUTION WATER
0.1 mL TO EACH TUBE
0.001
BOTTLE B
INCUBATE ALL TUBES AT 35° C ± 0.5°C FOR 24 HOURS
GAS IN INNER VIAL IS A + TEST RESULT

Fig. 11.13 Coliform bacteria test — raw water

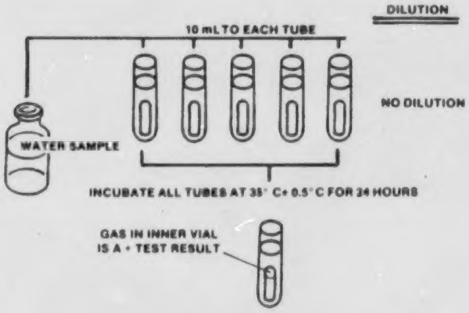

DILUTION
10 mL TO EACH TUBE
NO DILUTION
WATER SAMPLE
INCUBATE ALL TUBES AT 35° C ± 0.5°C FOR 24 HOURS
GAS IN INNER VIAL IS A + TEST RESULT

Fig. 11.14 Coliform bacteria test — drinking water

e. To make a 1/100 (0.01) dilution, add 1 m*L* of well mixed water sample to 99 m*L* of sterile buffered dilution water. Mix thoroughly by shaking. Add 1 m*L* from this bottle directly into each of five more lauryl tryptose broth tubes.

f. To make a 1/1000 (0.001) dilution, add 0.1 m*L* from the 1/100 dilution bottle directly into each of five more lauryl tryptose broth tubes.

The first time a sample is analyzed, twenty-five tubes of lauryl tryptose broth should be prepared. Once you find out what dilutions give usable results for determining the MPN index, you will only need to prepare fifteen tubes to analyze subsequent samples from the same source.

FOR DRINKING WATER SAMPLES

a. Shake the sample bottle vigorously twenty times before removing a sample volume.

b. Pipet 10 m*L* of sample directly into each of five tubes containing 10 m*L* of double-strength lauryl tryptose broth.

4. Incubation (Total Coliform)

a. 24-Hour Lauryl Tryptose (LT) Broth Presumptive Test

Place all inoculated LT broth tubes in 35°C ± 0.5°C incubator. After 24 ± 2 hours have elapsed, examine each tube for gas formation in inverted vial (inner tube). Mark plus (+) on report form such as shown in Figure 11.15 for all tubes that show presence of gas. Mark minus (−) for all tubes showing no gas formation. Immediately perform Confirmation Test on all positive (+) tubes (see Section C, BGB Confirmation Test). The negative (−) tubes must be reincubated for an additional 24 hours.

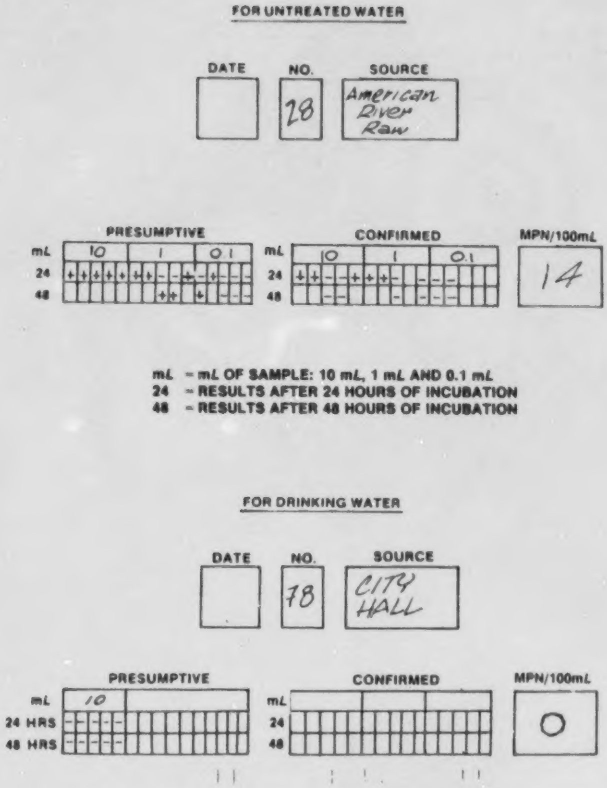
b. 48-Hour Lauryl Tryptose Broth Presumptive Test

Record both positive and negative tubes at the end of 48 ± 3 hours. Immediately perform Confirmation Test on all new positive tubes.

c. 24-Hour Brilliant Green Bile (BGB) Confirmation Test

Confirm all presumptive tubes that show gas at 24 or 48 hours. Transfer, with the aid of a sterile 3 mm platinum wire loop (sterile wood applicator or disposable loops may be used also), one loop-full of the broth from the lauryl tryptose broth tubes showing gas, and inoculate a corresponding tube of BGB (Brilliant Green Bile) broth by mixing the loop of broth in the BGB broth. Discard all positive lauryl tryptose broth tubes after transferring is completed.

Always sterilize inoculation loops and needles in flame immediately before transfer of culture; do not lay loop down or touch it to any nonsterile object before making the transfer. After sterilization in a flame, allow sufficient time for cooling, in the air, to prevent the heat of the loop from killing the bacterial cells being transferred. Wooden sterile applicator sticks also are used to transfer cultures, especially in the field where a flame is not available for sterilization. If using hardwood applicators, sterilize by autoclaving before use and discard after each transfer.



FOR UNTREATED WATER

DATE	NO.	SOURCE
	28	American River Raw

PRESUMPTIVE

mL	10					1					0.1				
24	+	+	+	+	+	+	+	–	–	+	–	+	–	–	–
48								+	+		+		–	–	–

CONFIRMED

mL	10					1					0.1				
24	+	+	–	–	+	+	+	–		–	–	–			
48			–	–				–		–	–	–			

MPN/100mL: 14

mL = mL OF SAMPLE: 10 mL, 1 mL AND 0.1 mL
24 = RESULTS AFTER 24 HOURS OF INCUBATION
48 = RESULTS AFTER 48 HOURS OF INCUBATION

FOR DRINKING WATER

DATE	NO.	SOURCE
	78	CITY HALL

PRESUMPTIVE

mL	10														
24 HRS	–	–	–	–	–										
48 HRS	–	–	–	–	–										

CONFIRMED

mL															
24															
48															

MPN/100mL: 0

Fig. 11.15 Recorded coliform test results

After 24 hours have elapsed, inspect each of the BGB tubes for gas formation. Those with any amount of gas are considered positive and are so recorded on the data sheet. Negative BGB tubes are reincubated for an additional 24 hours.

d. 48-Hour Brilliant Green Bile Confirmation Test

(1) Examine tubes for gas at the end of the 48 ± 3 hour period. Record both positive and negative tubes.

(2) Complete reports by determining MPN Index and recording MPN on work sheets.

5. Recording Results

Results should be recorded on data sheets prepared especially for this test. Examples are shown in Figure 11.15.

6. Method of Calculating the Most Probable Number (MPN)

Select the highest dilution or inoculation with all positive tubes, before a negative tube occurs, plus the next two dilutions.

EXAMPLE NO. 1 (UNTREATED WATER) — Select the underlined inoculations.

mL of sample	10	1	0.1	0.01	0.001
dilutions	0	0	−1	−2	−3
positive tubes	5	1	0	0	0

Read MPN as	33 per 100 mL from Table 11.3
Report MPN as	33 per 100 mL

EXAMPLE NO. 2 (UNTREATED WATER) — Select the underlined inoculations (see Figure 11.16).

mL of sample	10	1	0.1	0.01	0.001
dilutions	0	0	−1	−2	−3
positive tubes	5	5	2	0	0

Read MPN as	49 per 100 mL from Table 11.3
Report results as	490/100 mL

We added one zero to 49 because we started with the 1 mL sample and Table 11.3 begins with one dilution column to the left.

For Example No. 2

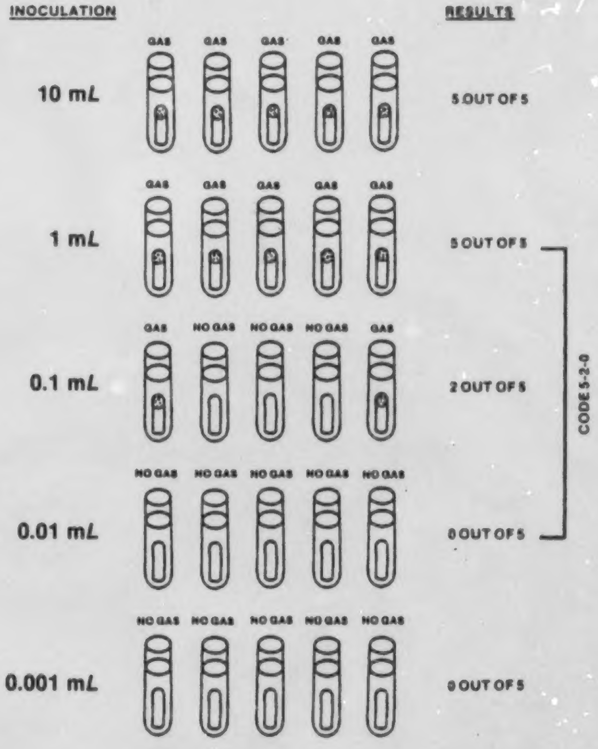

INOCULATION
RESULTS
10 mL
GAS
GAS
GAS
GAS
GAS
5 OUT OF 5
1 mL
GAS
GAS
GAS
GAS
GAS
5 OUT OF 5
0.1 mL
GAS
NO GAS
NO GAS
NO GAS
GAS
2 OUT OF 5
0.01 mL
NO GAS
NO GAS
NO GAS
NO GAS
NO GAS
0 OUT OF 5
0.001 mL
NO GAS
NO GAS
NO GAS
NO GAS
NO GAS
0 OUT OF 5
CODE 5-2-0

Fig. 11.16 Results of coliform test — untreated water

(Coliform)

TABLE 11.3

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-m*L*, FIVE 1-m*L* AND FIVE 0.1-m*L* PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-m*L* portions	Five 1-m*L* portions	Five 0.1-m*L* portions	(organisms per 100 m*L*)
0	0	0	0
0	0	1	2
0	0	2	4
0	1	0	2
0	1	1	4
0	1	2	6
0	2	0	4
0	2	1	6
0	3	0	6
1	0	0	2
1	0	1	4
1	0	2	6
1	0	3	8
1	1	0	4
1	1	1	6
1	1	2	8
1	2	0	6
1	2	1	8
1	2	2	10
1	3	0	8
1	3	1	10
1	4	0	11
2	0	0	5
2	0	1	7
2	0	2	9
2	0	3	12
2	1	0	7
2	1	1	9
2	1	2	12
2	2	0	9
2	2	1	12
2	2	2	14
2	3	0	12
2	3	1	14
2	4	0	15
3	0	0	8
3	0	1	11
3	0	2	13
3	1	0	11
3	1	1	14
3	1	2	17
3	1	3	20
3	2	0	14
3	2	1	17
3	2	2	20
3	3	0	17
3	3	1	21

TABLE 11.3 (Cont.)

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-m*L*, FIVE 1-m*L* AND FIVE 0.1-m*L* PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-m*L* portions	Five 1-m*L* portions	Five 0.1-m*L* portions	(organisms per 100 m*L*)
3	4	0	21
3	4	1	24
3	5	0	25
4	0	0	13
4	0	1	17
4	0	2	21
4	0	3	25
4	1	0	17
4	1	1	21
4	1	2	26
4	2	0	22
4	2	1	26
4	2	2	32
4	3	0	27
4	3	1	33
4	3	2	39
4	4	0	34
4	4	1	40
4	5	0	41
4	5	1	48
5	0	0	23
5	0	1	31
5	0	2	43
5	0	3	58
5	0	4	76
5	1	0	33
5	1	1	46
5	1	2	63
5	1	3	84
5	2	0	49
5	2	1	70
5	2	2	94
5	2	3	120
5	2	4	148
5	2	5	177
5	3	0	79
5	3	1	110
5	3	2	140
5	3	3	180
5	3	4	210
5	3	5	250
5	4	0	130
5	4	1	170
5	4	2	220
5	4	3	280

(Coliform)

TABLE 11.3 (Cont.)

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS IN A PLANTING SERIES OF FIVE 10-mL, FIVE 1-mL AND FIVE 0.1-mL PORTIONS OF SAMPLE

Number of tubes giving positive reaction out of			MPN Index
Five 10-mL portions	Five 1-mL portions	Five 0.1-mL portions	(organisms per 100 mL)
5	4	4	350
5	4	5	430
5	5	0	240
5	5	1	350
5	5	2	540
5	5	3	920
5	5	4	1600
5	5	5	≥2400

EXAMPLE NO. 3 (DRINKING WATER SAMPLE) — (see Figure 11.17)

mL of sample	10
positive tubes	1
Read MPN as	2.2 per 100 mL from Table 11.4

For Example No. 3

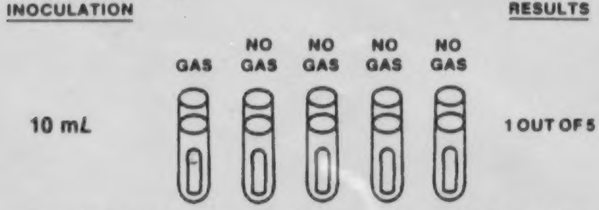


Figure 11.17 Results of coliform test — drinking water

TABLE 11.4

MPN INDEX FOR VARIOUS COMBINATIONS OF POSITIVE AND NEGATIVE RESULTS WHEN FIVE 10 mL PORTIONS ARE USED

Number of tubes giving positive reaction out of 5 of 10 mL each	MPN Index per 100 mL
0	less than 2.2
1	2.2
2	5.1
3	9.2
4	16
5	greater than 16

When you wish to summarize with a single MPN value the results from a series of samples, the arithmetic mean, the median, or the geometric mean may be used (see following sections for *FORMULAS* and *EXAMPLES*).

FORMULAS

The MPN for combinations not appearing in the table given or for other combinations of tubes or dilutions may be estimated by the formula:

$$\text{MPN/100 mL} = \frac{(\text{No. of positive tubes})\ (100)}{\sqrt{\begin{pmatrix}\text{mL sample in}\\ \text{negative tubes}\end{pmatrix} \times \begin{pmatrix}\text{mL sample in}\\ \text{all tubes}\end{pmatrix}}}$$

Coliform results may be summarized with a single MPN value by using the arithmetic mean, median, or geometric mean. The arithmetic mean is often called the average.

$$\text{Mean} = \frac{\text{Sum of items or values}}{\text{Number of items or values}}$$

The median is the middle value in a set or group of data. There are just as many values larger than the median as there are smaller than the median. To determine the median, the data should be written in ascending (increasing) or descending (decreasing) order and the middle value identified.

Median = Middle value of a group of data

The median and geometric mean are used when a sample contains a few very large values. This frequently happens when measuring the MPN of raw water. If **X** is a measurement (MPN) and **n** is the number of measurements, then

$$\text{Geometric Mean} = [(X_1)(X_2)(X_3) \ldots\ldots\ldots\ldots\ldots (X_n)]^{1/n}$$

This calculation can be easily performed on many electronic calculators

EXAMPLE 4

The results from an MPN test using five fermentation tubes for each dilution on a sample of water were as follows:

Sample Size, mL	10	1.0	0.1
Number of Positive Tubes Out of Five Tubes	3+	1+	0+

Determine the information necessary to solve the formula:

$$\text{MPN/100 m}L = \frac{(\text{No. of positive tubes})\ (100)}{\sqrt{\begin{pmatrix}\text{m}L\text{ sample in}\\ \text{negative tubes}\end{pmatrix} \times \begin{pmatrix}\text{m}L\text{ sample in}\\ \text{all tubes}\end{pmatrix}}}$$

1. Number of positive tubes. There were 3 positive tubes with 10 mL of sample and 1 positive tube with 1 mL of sample. Therefore, 3 + 1 = 4 positive tubes.

2. Determine the mL of sample in negative tubes.

Sample Size, mL	Number of Negative Tubes	mL of Sample in Negative Tubes	
10 mL	2–	(10 mL)(2)	= 20 mL
1.0mL	4–	(1.0 mL)(4)	= 4 mL
0.1 mL	5–	(0.1 mL)(5)	= 0.5 mL
		Total	= 24.5 mL

3. Determine the mL of sample in all tubes.

Sample Size, mL	Number of Tubes	mL of Sample in All Tubes	
10 mL	5	(10 mL)(5)	= 50 mL
1.0 mL	5	(1.0 mL)(5)	= 5 mL
0.1 mL	5	(0.1 mL)(5)	= 0.5 mL
		Total	= 55.5 mL

4. Estimate the MPN/100 mL.

$$\text{MPN/100 m}L = \frac{(\text{No. of positive tubes})\ (100)}{\sqrt{\begin{pmatrix}\text{m}L\text{ sample in}\\ \text{negative tubes}\end{pmatrix} \times \begin{pmatrix}\text{m}L\text{ sample in}\\ \text{all tubes}\end{pmatrix}}}$$

$$= \frac{(4)(100)}{\sqrt{(24.5\text{ m}L)(55.5\text{ m}L)}}$$

$$= \frac{400}{36.87}$$

$$= 10.8\text{ MPN Coliforms/100 m}L$$

$$= 11\text{ MPN Coliforms/100 m}L$$

EXAMPLE 5

Results from MPN tests during one week were as follows:

Day	S	M	T	W	TH	F	S
MPN/100 mL	2	8	14	5	10	26	4

Estimate the (1) mean, (2) median, and (3) geometric mean of the data in MPN/100 mL.

1. Calculate the mean.

$$\text{Mean, MPN/100 m}L = \frac{\text{Sum of All MPNs}}{\text{Number of MPNs}}$$

$$= \frac{2+8+14+6+10+26+4}{7}$$

$$= \frac{70}{7}$$

$$= 10\text{ MPN/100 m}L$$

2. To determine the median, rearrange the data in ascending (increasing) order and select the middle value (three will be smaller and three will be larger in this example).

Order	1	2	3	4	5	6	7
MPN/100 mL	2	4	6	8	10	14	26
				↑			

Median, MPN/100 mL = Middle value of a group of data
= 8 MPN/100 mL

3. Calculate the geometric mean for the given data.

$$\text{Geometric Mean, MPN/100 m}L = [(X_1)(X_2)(X_3)(X_4)(X_5)(X_6)(X_7)]^{1/7}$$
$$= [(2)(8)(14)(6)(10)(26)(4)]^{1/7}$$
$$= [1,397,760]^{1/7}$$
$$= 7.5\text{ MPN/100 m}L$$

4. *SUMMARY*

1. Mean = 10 MPN/100 mL
2. Median = 8 MPN/100 mL
3. Geometric Mean = 7.5 MPN/100 mL

As you can see from the summary, the geometric mean more nearly describes most of the MPNs. This is the reason why the geometric mean is sometimes used to describe the results of MPN tests when there are a few very large values.

Membrane Filter Method

1. *GENERAL DISCUSSION*

In addition to the fermentation tube test for coliform bacteria, another test is used for these same bacteria in water analysis. This test uses a cellulose ester filter, called a membrane filter, the pore size of which can be manufactured to close tolerances. Not only can the pore size be made to selectively trap bacteria from water filtered through the membrane, but nutrients can be diffused up through the membrane to grow these bacteria into colonies. These colonies are recognizable as coliform because the nutrients include fuchsin dye which peculiarly colors the colony. Knowing the number of colonies and the volume of water filtered, the operator can then compare the water tested with water quality standards.

A two step pre-enrichment technique is included at the end of this section for samples which have been chlorinated. Chlorinated bacteria which are still living have had their enzyme systems damaged and require a 2-hour enrichment media before contact with the selective M-Endo Media.

2. *MATERIALS NEEDED*

a. One sterile membrane filter having a 0.45μ pore size.

b. One sterile 47 mm petri dish with lid.

c. One sterile funnel and support stand.

d. Two sterile pads.

e. One receiving flask (side-arm, 1000 mL).

f. Vacuum pump, trap, suction or vacuum gage, connection sections of plastic tubing, glass "T" hose clamp to adjust pressure bypass.

g. Forceps (round-tipped tweezers), alcohol, Bunsen Burner, grease pencil.

h. Sterile buffered distilled water for rinsing.

i. M-Endo Media.

j. Sterile pipets — two 5 mL graduated pipets and one, 1-mL pipet for sample or one 10-mL pipet for larger sample. Quantity of one-mL pipets if dilution of sample is necessary. Also, quantity of dilution water blanks if dilution of sample is necessary.

k. One moist incubator at 35°C; auxiliary incubator dish with cover.

l. Enrichment media — lauryl tryptose broth (for pre-enrichment technique).

(Coliform)

m. A binocular wide-field dissecting microscope is recommended for counting. The light source should be a cool white fluorescent lamp.

3. *SELECTION OF SAMPLE SIZE*

Size of the sample will be governed by the expected bacterial density. An ideal quantity will result in the growth of between 20 to 80 coliform colonies, but not more than 200 bacterial colonies of all types. The table below lists suggested sample volumes for MF total coliform testing.

	Quantities Filtered (m*L*)				
	100	10	1	0.1	0.01
Well Water	x				
Drinking Water	x				
Lakes	x	x	x		
Rivers		x	x	x	x

When less than 20 m*L* of sample is to be filtered, a small amount of sterile dilution water should be added to the funnel before filtration. This increase in water volume aids in uniform dispersion of the sample over the membrane filter.

4. *PREPARATION OF PETRI DISH FOR MEMBRANE FILTER*

   a. Sterilize forceps by dipping in alcohol and passing quickly through Bunsen burner flame to burn off the alcohol. An alcohol burner may be used also.

   b. Place sterile absorbent pad into sterile petri dish.

   c. Add 1.8 to 2.0 m*L* M-Endo Medium to absorbent pad using a sterile pipet. Remove excess media.

5. *PROCEDURE FOR FILTRATION OF UNCHLORINATED SAMPLES*

All filtrations and dilutions of water specimens must be accurate and should be made so that no contaminants from the air, equipment, clothes or fingers reach the specimen either directly or by way of the contaminated pipet.

   a. Secure tubing from pump and bypass to receiving flask. Place palm of hand on flask opening and start pump. Adjust suction to ¼ atmosphere with hose clamp on pressure bypass. Turn pump switch to OFF.

   b. Set sterile filter-support-stand and funnel on receiving flask. Loosen wrapper. Rotate funnel counterclockwise to disengage pin. Recover with wrapper.

   c. Place petri dish on bench with lid up. Write identification on lid with grease pencil.

   d. Unwrap sterile pad container. Light Bunsen burner.

   e. Unwrap membrane filter container.

   f. Sterilize forceps by dipping in alcohol and passing quickly through Bunsen burner to burn off the alcohol.

   g. Center membrane filter on filter stand with forceps after lifting funnel. Membrane filter with printed grid should show grid uppermost (Fig. I, next page).

   h. Replace funnel and lock against pin (Fig. II).

   i. Shake sample or diluted sample. Measure proper *ALIQUOT*[13] with sterile pipet and add to funnel.

   j. Add a small amount of the sterile dilution water to funnel. This will help check for leakage and also aid in dispersing small volumes (Fig. III).

   k. Now start vacuum pump.

   l. Rinse filter with three 20- to 30-m*L* portions of sterile dilution water.

   m. When membrane filter appears barely moist, switch pump to OFF.

   n. Sterilize forceps as before.

   o. Remove membrane filter with forceps after first removing funnel as before (Fig. I).

   p. Center membrane filter on pad containing M-Endo Media with a rolling motion to insure water seal. Inspect membrane to insure no captured air bubbles are present (Fig. IV).

   q. Place *INVERTED* petri dish in incubator for 22 ± 2 hours. Incubate at 35°C.

6. *PROCEDURE FOR COUNTING MEMBRANE FILTER COLONIES*

   a. Remove petri dish from incubator.

   b. Remove lid from petri dish.

   c. Turn so that your back is to window.

   d. Tilt membrane filter in base of petri dish so that green and yellow-green colonies are most apparent. Direct sunlight has too much red to facilitate counting.

   e. Count individual colonies utilizing an overhead fluorescent light. The typical colony has a pink to dark red color with a metallic surface sheen. The sheen area may vary from a small pin-head size to complete coverage of the colony surface. Only those showing this sheen should be counted.

   f. Report total number of "coliform colonies" on work sheet. Use the membranes that show from 20 to 90 colonies and do not have more than 200 colonies of all types (including non-sheen or, in other words, non-coliforms).

EXAMPLE:

A total of 42 colonies grew after filtering a 10 m*L* sample.

$$\text{Bacteria/100 m}L = \frac{\text{No. of colonies counted} \times 100 \text{ m}L}{\text{Sample volume filtered, m}L \times 100 \text{ m}L}$$

$$= \frac{(42 \text{ colonies})(100 \text{ m}L)}{(10 \text{ m}L)(100 \text{ m}L)}$$

$$= \frac{(4.2)(100 \text{ m}L)}{100 \text{ m}L}$$

$$= 420 \text{ per } 100 \text{ m}L$$

SPECIAL NOTE:

Inexperienced persons often have great difficulty with connected colonies, with mirror reflections of fluorescent tubes (which are confused with metallic sheen), and with water condensate and particulate matter which are occasionally mistaken for colonies. Thus there is a

---

[13] *Aliquot (AL-li-kwot). Portion of sample.*

OUTLINE OF PROCEDURE FOR INOCULATION OF MEMBRANE FILTER

Fig. I

1. Center membrane filter on filter holder. Handle membrane only on outer $^3/_{16}$ inch with forceps sterilized before use in ethyl or methyl alcohol and passed lightly through a flame.

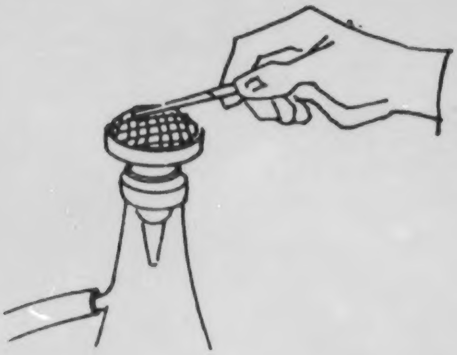


Fig. II

2. Place funnel onto filter holder.

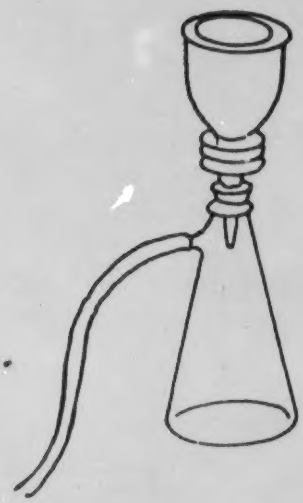
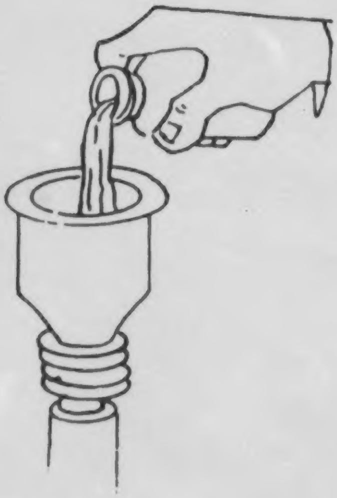
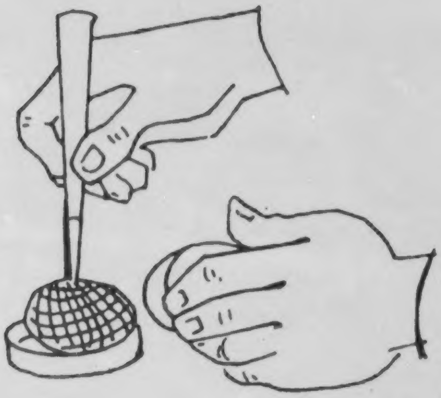


Fig. III



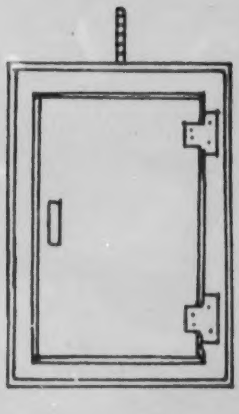
3. Pour or pipet sample aliquot into funnel. Avoid spattering. After suction is applied rinse four times with sterile buffered distilled water.

Fig. IV



4. Remove membrane filter from filter holder with sterile forceps. Place membrane on pad. Cover with petri top.

Fig. V



5. Incubate in inverted position for 22 ± 2 hours.
6. Count coliform appearing colonies on membrane.

(Coliform)

tendency for inexperienced persons to make errors on the high side in MF counts. At least five apparent coliform colonies should be transferred to lauryl tryptose broth tubes for verification as coliform organisms.

7. *PROCEDURE FOR FILTRATION OF CHLORINATED SAMPLES USING ENRICHMENT TECHNIQUE*

   a. Place a sterile absorbent pad in the upper half of a sterile petri dish and pipet 1.8 to 2.0 m*L* sterile lauryl tryptose broth. Carefully remove any surplus liquid.

   b. *ASEPTICALLY*[14] place the membrane filter through which the sample has been passed on the pad.

   c. Incubate the filter, without inverting the dish, for 1½ to 2 hours at 35°C in an atmosphere of 90 percent humidity (damp paper towels added to a plastic container with a snap-on lid can be used to produce the humidity).

   d. The enrichment culture is then removed from the incubator. A fresh sterile absorbent pad is placed in the bottom half of the petri dish and saturated with 1.8 to 2.0 m*L* M-Endo Broth.

   e. The membrane filter is transferred to the new pad. The used pad of lauryl tryptose may be discarded.

   f. Invert the dish and incubate for 20 to 22 hours at 35 ± 0.5°C.

   g. Count colonies as in previous method.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3H Why are drinking waters not tested for specific pathogens (such as typhoid and dysentery)?

11.3I To perform coliform tests, how would you decide how many samples to test?

11.3J Why should sodium thiosulfate be added to coliform sample bottles?

11.3K Steam autoclaves sterilize (kill all organisms) at a pressure of ____ psi and temperature of ____ °C during a ____ minute time period (at sea level).

11.3L Estimate the Most Probable Number (MPN) of coliform group bacteria for a raw water sample from the following test results:

m*L* of sample	1	0.1	0.01	0.001
Dilutions	0	−1	−2	−3
Readings (+ tubes)	5	5	3	1

11.3M How is the number of coliforms estimated by the membrane filter method?

11.3N What are the incubation conditions for the membrane filter method?

End of Lesson 4 of 5 Lessons
on
LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. LABORATORY PROCEDURES

(Lesson 4 of 5 Lessons)

Write the answers to these questions in your notebook. The question numbering continues from Lesson 3.

15. What is the purpose of the coliform group bacteria test?
16. How would you determine the number of dilutions for an MPN test?
17. What factors can cause errors when counting colonies on membrane filters?
18. How can questionable colonies on membrane filters be verified as coliform colonies?

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[14] *Aseptic (a-SEP-tick). Free from the living germs of disease, fermentation, or putrefaction. Sterile.*

Chapter 11. LABORATORY PROCEDURES

(Lesson 5 of 5 Lessons)

5. Hardness

A. Discussion

Hardness is caused principally by the calcium and magnesium ions commonly present in water. Hardness may also be caused by iron, manganese, aluminum, strontium, and zinc if present in significant amounts. Because only calcium and magnesium are present in significant concentrations in most waters, hardness can be defined as the total concentration of calcium and magnesium ions expressed as the calcium carbonate ($CaCO_3$) equivalent.

There are two types or classifications of water hardness: carbonate and non-carbonate. Carbonate hardness is due to calcium/magnesium bicarbonate or carbonate. Hardness that is due to calcium/magnesium sulfate, chloride, or nitrate is termed non-carbonate.

Hard water can cause incrustations (scale) when the water evaporates, or when heated in household hot water heaters and piping. Hardness-producing substances in water also combine with soap to form insoluble precipitates. The common method of minimizing these and other problems due to hardness is water supply softening. This procedure is discussed in Chapter 14, "Softening," in Volume II, of *WATER TREATMENT PLANT OPERATION.*

B. What is Tested

	Common Range mg/L as $CaCO_3$
Surface Water	30 to 500*
Well Water	80 to 500*

*Levels of hardness depend on local conditions.

C. Apparatus

Buret (25 mL)
Buret support
Graduated cylinder (100 mL)

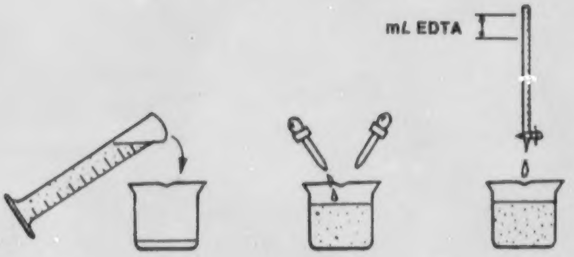
Beaker (250 mL)
Magnetic stirrer
Magnetic stir-bar
Flask, Erlenmeyer (500 mL)
Funnel
Hot plate
Flask, volumetric (1000 mL)

D. Reagents

NOTE: Standardized solutions are available already prepared from laboratory chemical supply companies.

1. Buffer solution.
2. Standard EDTA or CDTA titrant. EDTA is disodium ethylene-diaminetetraacetate dihydrate, also called (ethylenedinitrilo)-tetraacetic acid disodium salt. CDTA is disodium-CTDA (1,2 cyclohexanediaminetetraacetic acid).
3. Indicator solution.

OUTLINE OF PROCEDURE



1. Add 50 mL of sample to clean beaker.
2. Add 2 mL of buffer and 2 drops of indicator.
3. Titrate with EDTA to blue end point.

E. Procedure

1. Take a clean beaker and add 50 mL of sample.
2. Add 2 mL of buffer solution.
3. Add 2 drops indicator solution.
4. Titrate with standard EDTA solution until the last reddish tinge disappears from the solution. The solution is pure blue when the end point is reached.
5. Calculate total hardness.

F. Example

Results from water hardness testing of a well water sample were as follows:

Sample size = 50 mL
mL of EDTA titrant used, A = 10.5 mL

G. Calculation

$$\text{Hardness, mg/}L\text{ as }CaCO_3 = \frac{A \times 1{,}000}{mL\text{ of sample}}$$

$$= \frac{(10.5\ mL) \times 1{,}000}{50\ mL\text{ of sample}}$$

$$= 210\ mg/L$$

H. Precautions

1. Some metal ions interfere with this procedure by causing fading or indistinct end points. In these cases, an inhibitor reagent should be used. You may titrate with either standard CDTA solution or EDTA solution.
2. The titration should be completed within five minutes to minimize $CaCO_3$ precipitation.
3. A sample volume should be selected that requires less than 15 mL of EDTA titrant to be used.

(Jar Test)

4. For titrations of samples containing low hardness concentrations (less than 150 mg/L, as $CaCO_3$) a larger sample volume should be used.

I. Reference

See page 194, *STANDARD METHODS*, 15th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3O What are the principal hardness-causing ions in water?

11.3P What problems are caused by hardness in water?

6. Jar Test

A. Discussion

Jar tests are tests designed to show the effectiveness of chemical treatment in a water treatment facility. Many of the chemicals we add to water can be evaluated on a small laboratory scale by the use of a jar test. The most important of these chemicals are those used for coagulation such as alum and polymers. Using the jar test, the operator can approximate the correct coagulant dosage for plant use when varying amounts of turbidity, color, or other factors indicate raw water quality changes. The jar test is also a very useful tool in evaluating new coagulants or polymers being considered for use on a plant scale.

B. What is Tested

Raw water, for optimum coagulant dose, which varies depending on coagulant(s) used and water quality.

C. Apparatus

1. A stirring machine with six paddles capable of variable speeds from 0 to 100 revolutions per minute (rpm).
2. An illuminator located underneath the stirring mechanism (optional).
3. Beakers (1000 mL).
4. Pipets (10 mL)
5. Flask, volumetric (1000 mL)
6. Balance, analytical.

D. Reagents

1. Stock Coagulant Solution
   a. Dry alum, $Al_2(SO_4)_3 \cdot 14.3\ H_2O$.[15] Dissolve 10.0 g dry alum (17 percent) in 600 mL distilled water contained in a 1000 mL volumetric flask. Fill to mark. This solution contains 10,000 mg/L or 10 mg/mL.
   b. Liquid alum, $Al_2(SO_4)_3 \cdot 49.6\ H_2O$.[15] The operator should verify the strength of the alum with a hydrometer. Liquid alum is usually shipped as 8.0 to 8.5 percent Al_2O_3 and contains about 5.36 pounds of dry aluminum sulfate (17 percent dry) per gallon (specific gravity 1.325). This converts to 624,336 mg/L. Therefore, add 15.6 mL liquid alum to a 1000 mL volumetric flask and fill to mark. This solution contains 10,000 mg/L or 10 mg/mL.
   c. Table 11.5 indicates the strengths of stock solutions for various dosages.

TABLE 11.5 DRY CHEMICAL CONCENTRATIONS USED FOR JAR TESTING[a]

Approx. Dosage Required, mg/L[b]	Grams/Liter to Prepare[c]	1 mL Added to 1 Liter Sample Equals	Stock Solution Conc., mg/L (%)
1-10 mg/L	1 gm/L	1 mg/L	1,000 mg/L (0.1%)
10-50 mg/L	10 gm/L	10 mg/L	10,000 mg/L (1.0%)
50-500 mg/L	100 gm/L	100 mg/L	100,000 mg/L (10.0%)

[a] From *JAR TEST* by E. E. Arasmith, Linn-Benton Community College, Albany, Oregon.

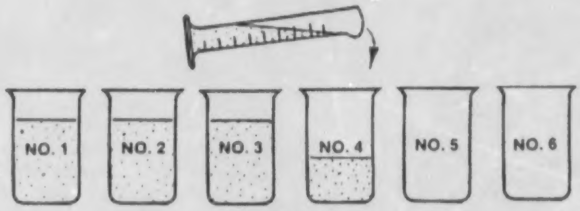
[b] Use this column which indicates the approximate dosage required by raw water to determine the trial dosages to be used in the jar test.

[c] This column indicates the grams of dry chemical that should be used when preparing the stock solution. The stock solution consists of the chemical plus enough water to make a one-liter solution.

E. Procedure

1. Collect two gallons (8 liters) sample of the water to be tested.
2. Immediately measure six 1000-mL quantities and place into each of six 1000-mL beakers.
3. Place all six beakers on stirring apparatus.
4. With a measuring pipet, add increasing dosages of coagulant solution to the beakers as rapidly as possible. Select a series of dosages so that the first beaker will represent an under-dose and the last an over-dose.
5. With stirring paddles lowered into the beakers, start stirring apparatus and operate it for one minute at a speed of 80 rpm.[16]
6. Reduce the stirring speed for the next 30 minutes to 20 rpm.[16]

OUTLINE OF PROCEDURE



1. Add 1000 mL to each of 6 beakers.

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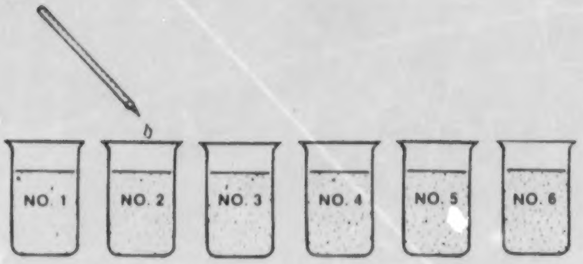
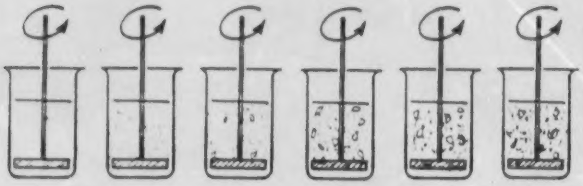
[15] *Values of 14.3 H_2O and 49.6 H_2O were obtained from ALUMINUM SULFATE published by Stauffer Chemicals. Actual values for commercial alum purchased by your water treatment plant may vary slightly.*

[16] *Use stirring speeds and times which are similar to actual conditions in your water treatment plant.*



2. Add increasing dosages of coagulant.



3. Stir for appropriate time period.
Evaluate floc quality.

7. Observe and evaluate each beaker as to that specific dosage's floc quality. Record results.

8. Stop the stirring apparatus and allow samples in beakers to settle for 30 minutes.[16] Observe the floc settling characteristics. A hazy sample indicates poor coagulation. Properly coagulated water contains floc particles that are well-formed and dense, with the liquid between the particles clear. Describe results as poor, fair, good, or excellent.

F. Precautions

Without going to extreme measures, it is very difficult to duplicate in the jar test exactly what is happening on a plant scale. The jar test, therefore, should be used as an indication of what is to be expected on a larger scale in a water treatment plant.

There are a number of tests that can be performed to improve the jar test and the interpretation of the results. These tests include:

1. Alkalinity (before and after),
2. pH (before and after),
3. Turbidity of *SUPERNATANT*[17] (before and after), and
4. Filtered turbidity of supernatant.

See Figure 11.18 for a helpful jar test data sheet.

After estimating the optimum coagulant dosage, run another jar test with the optimum coagulant dosage constant, but vary the pH. These results will give you the optimum pH.

Alkalinity must be monitored very carefully before and after the jar test. Alkalinity must always be *AT LEAST* half of the coagulant dose. For example, if the optimum coagulant dose is 50 mg/*L*, the total alkalinity must be at least 25 mg/*L*. If the natural alkalinity is less than 25 mg/*L*, adjust the total alkalinity up to 25 mg/*L* by adding lime. For additional information on how to calculate the amount of lime needed to increase the alkalinity, see page 174, Section 5.243, "Arithmetic for Solids-Contact Clarification," and page 175, *EXAMPLE 6*.

G. Example

A sample of river water was collected for jar test analysis to determine the "optimum" alum dosage for effective coagulation.

The following series of alum dosage was added:

Beaker No.	m*L* alum solution added	Alum added, mg/*L*
1	1.0	10
2	1.2	12
3	1.4	14
4	1.6	16
5	1.8	18
6	2.0	20

H. Interpretation of Results

Results of the above jar testing were recorded as follows:

Beaker No.	Alum Dose, mg/*L*	Floc Quality
1	10	poor
2	12	fair
3	14	good
4	16	excellent
5	18	excellent
6	20	good

The above results seem to indicate that a dose of 16 or 18 mg/*L* would be optimum. The operator should, however, verify this result with visual observation of what is actually happening in the flocculation basin.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3Q What is the purpose of the jar test?

11.3R What stirring speeds are used during the jar tests for optimum alum dosage?

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[17] *Supernatant (sue-per-NAY-tent). Liquid removed from settled sludge or floc. Supernatant commonly refers to the liquid between the sludge or floc on the bottom and the water surface of a basin or container (jar).*

JAR TEST DATA SHEET

SOURCE:
TIME:
COAGULANT:
DATE:
COAGULANT AID:
pH ADJUST:
ANALYST:

		TEMP	TURB	pH	ALKA					DESCRIPTION OF FLOC IN JARS								HARDNESS	
JAR NUMBER	SAMPLE SIZE	START / FINISH	START / FINISH	START / FINISH	START / FINISH	FILTERED TURBIDITY	COAG DOSE	COAG-AID DOSE	ADJUSTED pH	1ST APPEAR	5 MIN	10 MIN	15 MIN	20 MIN	25 MIN	30 MIN	45 MIN	START / FINISH	COMMENTS
1																			
2																			
3																			
4																			
5																			
6																			

CODE: VS = VERY SMALL; S = SMALL; M = MEDIUM
D = DENSE; VD = VERY DENSE; SP = SPARCE
L = LARGE; VL = VERY LARGE

Fig. 11.18 Typical jar test data sheet

7. pH

A. Discussion

The pH of a water indicates the intensity of its acidic or basic intensity. The pH scale runs from 0 to 14. Water having a pH of 7 is at the midpoint of the scale and is considered neutral. Such a water is neither acidic nor basic. A pH of greater than 7 indicates basic water. The stronger the basic intensity, the greater the pH. The opposite is true of the acidity. The stronger the intensity of the acidity, the lower will be the pH.

pH SCALE

0 ← INCREASING ACID ------ 7 ---- INCREASING BASE → 14
1 ← 2 ← 3 ← 4 ← 5 ← 6 /\ 8 → 9 → 10 → 11 → 12 → 13
← Neutral →

Mathematically, pH is the logarithm of the reciprocal of the hydrogen ion activity, or the negative logarithm of the hydrogen ion activity.

$$pH = \log \frac{1}{(H^+)} = -\log (H^+)$$

For example, if a water has a pH of 1, then the hydrogen ion activity $(H^+) = 10^{-1} = 0.1$. If the pH is 7, then $(H^+) = 10^{-7} = 0.0000001$. A change in the pH of one unit is caused by changing the hydrogen ion level by a factor of 10 (ten times).

In a solution, both hydrogen ions (H^+) and the hydroxyl ions (OH^-) are always present. At a pH of 7, the activity of both hydrogen and hydroxyl ions equals 10^{-7} *MOLES*[18] per liter. When the pH is less than 7, the activity of hydrogen ions is greater than the hydroxyl ions.

pH plays an important role in the water treatment processes such as disinfection, coagulation, softening, and corrosion control. The pH test also indicates changes in raw and finished water quality.

B. What is Tested

	Common Range
Surface water	6.5 to 8.5
Finished water	7.5 to 9.0
Well water	6.5 to 8.0

C. Apparatus

1. pH meter
2. Glass electrode
3. Reference electrode
4. Magnetic stirrer
5. Magnetic stir-bar

D. Reagents

1. Buffer tablets for various pH value solutions (available from laboratory chemical supply houses).
2. Distilled water.

E. Procedure

1. Due to the difference between the various makes and models of pH meters commercially available, specific instructions cannot be provided for the correct operation of all instruments. In each case, follow the manufacturer's instructions for preparing the electrodes and operating the instrument.
2. *STANDARDIZE THE INSTRUMENT AGAINST A BUFFER SOLUTION WITH A pH CLOSE TO THAT OF THE SAMPLE.*
3. Rinse electrodes thoroughly with distilled water after removal from buffer solution.
4. Place electrodes in sample and measure pH.
5. Remove electrodes from sample, rinse thoroughly with distilled water.
6. Immerse electrode ends in beaker of pH 7 buffer storage solution.
7. Turn meter to "standby" (or off).

F. Precautions

1. To avoid faulty instrument calibration, prepare fresh buffer solutions as needed, and at least one per week (from commercially available buffer tablets).
2. pH meter, buffer solution, and samples should all be near the same temperature because temperature variations will give somewhat erroneous results.
3. Watch for erratic results arising from electrodes, faulty connections, or fouling of electrodes with oily precipitated matter.
4. The temperature compensator on the pH meter adjusts the meter for changes in electrode response with temperature. However, the pH of water also changes with temperature and the pH meter cannot compensate for this change.
5. We recommend standardizing the pH meter using a pH buffer solution close to the pH of the sample. However, if you use another buffer solution with a different pH to determine the calibration of the pH meter for a range of pH values and the pH meter does not give the pH of the second buffer, follow manufacturer's directions to adjust the pH meter. This procedure is called adjusting the "slope" of the pH meter.

G. Interpretation of Results

The pH of water has a very important influence on the effectiveness of chlorine disinfection. Chlorination is a chemical reaction in which chlorine is an oxidizing agent. Chlorine is a more effective oxidant at lower pH values. Simply stated, a chlorine residual of 0.2 mg/*L* at a pH of 7 is just as effective a 1 mg/*L* at a pH of 10. Therefore, five times as much chlorine is required to do the same disinfecting job at pH 10 as it does at pH 7.

The finished water of some treatment facilities is adjusted with lime or caustic soda to the slightly basic pH for the purpose of minimizing corrosion in the distribution system.

H. Reference

See page 402, *STANDARD METHODS*, 15th Edition.

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[18] *Mole. The molecular weight of a substance, usually expressed in grams.*

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3S What does the pH of a water indicate?

11.3T What precautions should be exercised when using a pH meter?

8. Temperature

A. Discussion

Temperature is one of the most frequently taken tests in the water industry. Accurate water temperature readings are important not only for historical purposes but also because of its influence on chemical reaction rates, biological growth, dissolved gas concentrations, and water stability with respect to calcium carbonate, in addition to its acceptability by consumers for drinking.

B. What is Tested

	Common Range, °C
Raw and Treated Surface Water	5 to 25
Well Water	10 to 20

C. Apparatus

1. One NBS (National Bureau of Standards) thermometer for calibration of the other thermometers.
2. One Fahrenheit mercury filled, 1° subdivided thermometer.
3. One Celsius (formerly called Centigrade) mercury-filled, 1° subdivided thermometer.
4. One metal case to fit each thermometer.

NOTE: There are three types of thermometers and two scales.

SCALES

1. Fahrenheit, marked °F.
2. Celsius, marked °C (formerly Centigrade).

THERMOMETER STYLES

1. Total immersion. This type of thermometer must be totally immersed when read. Readings with this type of thermometer will change most rapidly when removed from the liquid to be recorded.
2. Partial immersion. This type thermometer will have a solid line (water-level indicator) around the stem below the point where the scale starts.
3. Dial. This type has a dial that can be easily read while the thermometer is still immersed. Dial thermometer readings should be checked (calibrated) against the NBS thermometer. Some dial thermometers can be recalibrated (adjusted) to read at a set temperature against the NBS thermometer.

D. Reagents

None required.

E. Procedure

1. Collect as large a volume of sample as is practical. The temperature will have less chance to change in a large volume than in a small container.
2. Immerse the thermometer to the proper depth. Do not touch the bottom or sides of the sample container with the thermometer.
3. Record temperature to the nearest fraction of a degree which can be estimated from the thermometer available.
4. When measuring the temperature of well water samples, allow the water to continuously overflow a small container (a polystyrene coffee cup is ideal). Place the thermometer in the cup. After there has been no change in the temperature reading for one minute, record the temperature. The temperature of water samples collected from a distribution system mainly depend on the soil temperature at the depth of the water main.

F. Precautions

To avoid breaking or damaging a glass thermometer, store it in a shielded metal case. Check your thermometer accuracy against the NBS certified thermometer by measuring the temperature of a sample with both thermometers simultaneously. Some of the poorer quality thermometers are substantially inaccurate (off as much as 6°F or 3°C).

G. Example

To measure the temperature of treated water, a sample was obtained in a gallon bottle, the thermometer immediately immersed, and a temperature of 15°C recorded after the reading became constant.

H. Calculation

Normally we measure and record temperatures using a thermometer with the proper scale. We could, however, measure a temperature in °C and convert to °F. The following formulas are used to convert temperatures from one scale to the other.

1. If we measure in °F and want °C,

$$°C = \frac{5}{9}(°F - 32)$$

2. If we measure in °C and want °F,

$$°F = \frac{9}{5}(°C) + 32$$

3. Sample Calculation

The measured treated water temperature was 15°C. What is the temperature in °F?

$$\begin{aligned} °F &= 9/5\ (°C) + 32 \\ &= 9/5\ (15°C) + 32 \\ &= 27 + 32 \\ &= 59°F \end{aligned}$$

I. Reference

See page 124, *STANDARD METHODS*, 15th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 523.

11.3U Why are temperature readings important?

11.3V Why should the thermometer remain immersed in the liquid while being read?

11.3W Why should thermometers be calibrated against an accurate NBS certified thermometer?

9. Turbidity

A. Discussion

The term turbidity is simply an expression of the physical cloudiness of water. Turbidity is caused by the presence of suspended matter such as silt, finely-divided organic and inorganic matter, and microscopic organisms such as algae.

The accepted method used to measure turbidity is called the nephelometric method. The nephelometric turbidimeter or nephelometer (Figure 11.19) is designed to measure particle-reflected light at an angle of 90 degrees to the source beam. The greater the intensity of scattered light, the higher the turbidity.

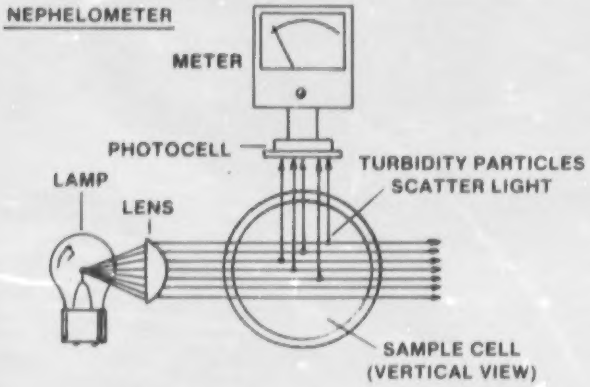

NEPHELOMETER
METER
PHOTOCELL
LAMP
LENS
TURBIDITY PARTICLES SCATTER LIGHT
SAMPLE CELL (VERTICAL VIEW)

Fig. 11.19 Nephelometer
(Permission of Hach Company)

The turbidity unit (NTU) is an empirical quantity which is based on the amount of light that is scattered by particles of a polymer reference standard called formazin. Formazin, a mixture of hydrazine and hexamethylenetetramine, produces particles which scatter light in a reproducible manner.

The turbidity measurement is one of the most important tests the plant operator performs. The Safe Drinking Water Act stipulates specific monitoring requirements for turbidity. Turbidity of treated surface water must be measured continuously or determined daily and the results reported to the appropriate authority. Turbidity testing is the most critical tool in recognizing changes in raw water quality, detecting problems in coagulation and sedimentation, and troubleshooting filtration problems.

The maximum contaminant level (MCL) for turbidity is one TU with five TU allowed under certain circumstances. Water treatment plant operators should strive to produce a finished water with a turbidity of 0.1 TU.

B. What is Tested

	Common Range, NTU
Untreated Surface Water	1 to 300
Filtered Water	0.03 to 0.50
Well Water	0.05 to 1.0+

C. Apparatus

1. Turbidimeter: To minimize differences in turbidity measurements, rigorous specifications for turbidimeters are necessary. The turbidimeter should have the following important characteristics:
   a. The turbidimeter should consist of a nephelometer with a light source illuminating the sample, and one or more photoelectric detectors to indicate the intensity of scattered light at a 90° angle with a "readout" device.
   b. The light source should be an intense tungsten filament lamp.
   c. The total distance traveled by the light through the sample should be less than about 5 centimeters.
   d. The instrument should have several measurement ranges. The instrument should be able to measure from 0 to 100 turbidity units, with sufficient sensitivity (on the lowest scale) to detect differences of 0.02 or less in filtered waters having turbidities of less than one unit.
2. Sample tubes. These are usually provided with the instrument.

D. Reagents

1. Turbidity-free water: Pass distilled water through a membrane filter having a pore size no greater than 0.2 microns (available from laboratory supply houses). Discard the first 200 m*L* collected. If filtration does not reduce turbidity of the distilled water, use unfiltered distilled water.
2. Stock Formazine turbidity suspension:[19]
   a. Solution I — Dissolve 1,000 g hydrazine sulfate in distilled water and dilute to 100 m*L* in a volumetric flask.
   b. Solution II — Dissolve 10.00 g hexamethylenetetramine in distilled water and dilute to 100 m*L* in a volumetric flask.
   c. In a 100 m*L* volumetric flask, add (using 5 m*L* volumetric pipets) 5.0 m*L* Solution I and 5.0 m*L* of Solution II. Mix and allow to stand 24 hours at 25°C. Then dilute to the mark and mix. The turbidity of this suspension is considered 400 NTU exactly.
   d. Prepare solutions and suspensions monthly.
3. Standard turbidity suspensions: Dilute 10.00 m*L* stock turbidity suspension to 100 m*L* with turbidity-free water. Prepare weekly. The turbidity of this suspension is defined as 40 NTU.
4. Dilute turbidity standards: Dilute portions of the standard turbidity suspension with turbidity-free water as required. Prepare weekly.

---

[19] *Stock turbidity suspensions that require no preparation are available from commercial suppliers and approved for use.*

E. Procedure

1. Turbidimeter calibration: the manufacturer's operating instructions should be followed. Measure your standard solutions on the turbidimeter covering the range of interest. If the instrument is already calibrated in standard *TURBIDITY UNITS*,[20] this procedure will check the accuracy of the calibration scales. At least one standard should be run in each instrument range to be used. Some instruments permit adjustments of sensitivity so that scale values will correspond to turbidities. Reliance on an instrument manufacturer's scattering standards for calibrating the instrument is not an acceptable practice unless they are in acceptably close agreement with prepared standards. If a pre-calibrated scale is not supplied, then calibration curves should be prepared for each usable range of the instrument.

2. Turbidities less than 40 units: Shake the sample to thoroughly disperse the suspended solids. Wait until air bubbles disappear, then pour the sample into the turbidimeter tube. Read the turbidity directly from the instrument scale or from the appropriate calibration curve.

3. Turbidities exceeding 40 units: Dilute the sample with one or more volumes of turbidity-free water until the turbidity falls below 40 units. The turbidity of the original sample is then computed from the turbidity of the diluted sample and the dilution factor.

F. Example

A reservoir sample was collected and the turbidity was found to be greater than 40 units when first checked. 30 m*L* of this sample was then diluted with 60 m*L* of turbidity-free water. This diluted sample showed a turbidity of 25 units.

NTU found in diluted sample, A = 25 NTU
m*L* of dilution water used, B = 60 m*L*
m*L* of sample volume taken for dilution, C = 30 m*L*

G. Calculation

$$\text{Nephelometric Turbidity Units (NTU)} = \frac{(A)\times(B+C)}{C}$$

$$= \frac{(25\text{ NTU})\times(60\text{ mL} + 30\text{ mL})}{30\text{ mL}}$$

$$= 75\text{ NTU}$$

H. Interpretation of Results

Report turbidity results as follows:

Turbidity Reading	Record to Nearest
0.0 to 1.0	0.05
1 to 10	0.1
10 to 40	1
40 to 100	5
100 to 1000	10
>1000	100

Notes and Precautions

1. Sample tubes must be kept scrupulously clean, both inside and out. Discard them when they become scratched or etched. Never handle them where the light strikes them.

2. Fill the tubes with samples and standards that have been agitated thoroughly, and allow sufficient time for bubbles to escape.

3. Turbidity should be measured in a sample as soon as possible to obtain accurate results. The turbidity of a sample can change after the sample is collected. Shaking the sample will not recreate the original turbidity.

J. Reference

See page 31, *STANDARD METHODS*, 15th Edition.

QUESTIONS

Write your answers in a notebook and then compare your answers with those on page 524.

11.3X What are the causes of turbidity in water?

11.3Y How is turbidity measured?

11.4 ARITHMETIC ASSIGNMENT

Turn to the Appendix at the back of this manual and read Section A.139, "Laboratory Procedures." Check all of the arithmetic in this section using an electronic pocket calculator. You should be able to get the same answers.

11.5 ADDITIONAL READING

1. *NEW YORK MANUAL*, Chapter 4, "Water Chemistry," Chapter 5, "Microbiology," and Chapter 21, "Laboratory Examinations of Water."
2. *TEXAS MANUAL*, Chapter 6, "Water Chemistry," and Chapter 12, "Laboratory Examinations."

11.6 WATER LABORATORY TESTS IN *WATER TREATMENT PLANT OPERATION*, Volume II

Laboratory procedures for the following tests are provided in *WATER TREATMENT PLANT OPERATION*, Volume II, Chapter 21, "Advanced Laboratory Procedures."

1. Algae Counts
2. Calcium
3. Chloride
4. Color
5. Dissolved Oxygen
6. Fluoride
7. Iron

---

[20] *Turbidity Units (TU) (ter-BID-it-tee). Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of scattered light. Although turbidity units are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.*

8. Manganese
9. Marble Test
10. Nitrate
11. Phosphate
12. Sulfate
13. Threshold Odor
14. Total Dissolved Solids
15. THMs

End of Lesson 5 of 5 Lessons on LABORATORY PROCEDURES

DISCUSSION AND REVIEW QUESTIONS

Chapter 11. LABORATORY PROCEDURES

(Lesson 5 of 5 Lessons)

Write the answers to these questions in your notebook before continuing with the Objective Test on page 524. The question numbering continues from Lesson 4.

19. What precautions should be considered when performing the hardness determination on a water sample?
20. How could you estimate the most effective dose of alum, or a polymer in a water treatment process?
21. What precautions should be exercised when taking temperature measurements?
22. Why should turbidity be measured in a sample as soon as possible?

HOW
HOW
WHAT
WHY

SUGGESTED ANSWERS

Chapter 11. LABORATORY PROCEDURES

ANSWERS TO QUESTIONS IN LESSON 1

Answers to questions on page 466.

11.0A Laboratory control tests are important because they provide the necessary information to control the treatment processes and insure a safe and good-tasting drinking water.

11.0B The prefix milli means 1/1000 (0.001) of the unit following.

11.0C The proper name of the chemical compound $CaCO_3$ is calcium carbonate.

Answers to questions on page 475.

11.1A Descriptions of laboratory glassware and their use or purpose.

Item	Description	Use or Purpose
1. Beakers	Short, wide cylinders in sizes from 1 mL to 4000 mL	Mixing chemicals
2. Graduated cylinders	Long, narrow cylinders in sizes from 5 mL to 4000 mL	Measuring volumes
3. Pipets	Small diameter graduated tubes, with a pointed tip, in sizes from 1.0 mL to 100 mL	Delivering accurate volumes
4. Burets	Long tubes with graduated walls and a stopcock in sizes from 10 mL to 1000 mL	Delivering and measuring accurate volumes used in "titrations"

11.1B Never heat graduated cylinders in an open flame because they may break.

11.1C A meniscus is the curve of the surface of a liquid in a small tube.

Answers to questions on page 477.

11.1D A "standard solution" is a solution in which the exact concentration of a chemical or compound in a solution is known.

11.1E Laboratory notebooks and worksheets help record data in an orderly manner.

11.1F Four sources or causes of poor quality of analytical data are:

1. Sloppy laboratory technique,
2. Deteriorated reagents and standards,
3. Poorly operating instruments, and
4. Calculation mistakes.

Answers to questions on page 483.

11.1G Six laboratory hazards are:

1. Hazardous materials,
2. Explosions,
3. Cuts and bruises,
4. Electric shock,
5. Fire, and
6. Burns (heat and chemical).

11.1H *NEVER* work all alone in the laboratory. Someone should always be available to help in case you should have an accident which blinds you, leaves you unconscious, or starts a fire you can't handle. If necessary have someone check on you regularly to be sure you are OK.

11.1I Dispose of small amounts of corrosive acids by pouring the acid down corrosion-resistant sinks and sewers using large quantities of water to dilute and flush the acid.

11.1J True. You may add acid to water, but never the reverse.

ANSWERS TO QUESTIONS IN LESSON 2

Answers to questions on page 486.

11.2A The greatest errors in laboratory tests are frequently caused by (1) improper sampling, (2) poor sample preservation, and (3) lack of enough mixing during testing.

11.2B A representative sample must be collected or the test results will have little significant meaning. The test results will not reflect actual water conditions. To efficiently operate a water treatment plant, the operator must rely on test results to indicate what is happening in the treatment process.

11.2C Sampling points in a distribution system should be selected in order to trace the course from the finished water source, whether it be a well or plant, through the transmission mains, and then through the major and minor arteries of the system.

Answers to questions on page 490.

11.2D The two general types of samples collected by water treatment personnel are (1) grab samples, and (2) composite samples.

11.2E Water quality indicators that are usually measured with a grab sample include (1) dissolved gases, (2) coliform bacteria, (3) residual chlorine, (4) temperature, and (5) pH.

11.2F Depth samples are collected by the use of a Kemmerer Sampler or similar device. The sampling device and container are lowered to the desired depth, then opened, filled, closed, and returned to the surface.

11.2G Samples should not be collected from taps surrounded by excessive foliage (leaves, flowers) or from taps that are dirty, corroded, or are leaking.

11.2H When collecting a sample, record the sample location, date and time of collection, name of collector, and any other pertinent information.

ANSWERS TO QUESTIONS IN LESSON 3

Answers to questions on page 493.

11.3A Chemicals used in water treatment that will cause changes in alkalinity include alum, chlorine, and lime.

11.3B Alkalinity is used in calculating chemical dosages needed in coagulation and water softening. Alkalinity must also be known to calculate corrosivity and to estimate carbonate hardness of a water.

Answers to questions on page 496.

11.3C The benefits of chlorinating water include:

1. Disinfection;
2. Improved quality of water due to chlorine reacting with iron, manganese, protein substances, sulfide, and many taste- and odor-producing compounds;
3. Control of microorganisms that might interfere with coagulation and flocculation;
4. Keeps filter media free of slime growths; and
5. Helps bleach out undesirable color.

11.3D A potential adverse effect from chlorination is the possibility of the formation of carcinogenic chlororganic compounds such as chloroform and other THMs.

Answers to questions on page 499.

11.3E Conditions that can cause variations in the chlorine demand of water include (1) the amount of chlorine applied, (2) time of contact, (3) pH, (4) temperature, (5) organics, and (6) reducing agents.

11.3F The operator uses the chlorine demand test to determine the best chlorine dosage to achieve specific chlorination objectives.

11.3G Chlorine Demand, mg/L = Chlorine Added, mg/L − Free Residual Chlorine, mg/L

= 2.0 mg/L − 0.4 mg/L

= 1.6 mg/L

ANSWERS TO QUESTIONS IN LESSON 4

Answers to questions on page 512.

11.3H Drinking waters are not tested for specific pathogens because the tests are very time-consuming and require special techniques and equipment.

11.3I The number of samples required for coliform tests is generally based on the population served by the water system.

11.3J Sodium thiosulfate should be added to sample bottles for coliform tests to neutralize any residual chlorine in the sample. If the residual chlorine is not neutralized, it would continue to be toxic to the coliform organisms remaining in the sample and give false (negative) results.

11.3K Steam autoclaves sterilize (kill all organisms) at a pressure of *15* psi and temperature of *121°C* during a *15* minute time period (at sea level).

11.3L

mL of sample	0.1	0.01	0.001
Dilutions	−1	−2	−3
Readings (+ tubes)	5	3	1

MPN = 11,000/100 mL

11.3M The number of coliforms is determined by counting the number of coliform appearing colonies grown on the membrane filter.

11.3N Incubate the filter, without incubating the dish for 1½ to 2 hours at 35°C in an atmosphere of 90 percent humidity. Transfer the membrane filter to a new pad enriched with M-Endo Broth. Invert the dish and incubate for 20 to 22 hours at 35 ± 0.5°C.

ANSWERS TO QUESTIONS IN LESSON 5

Answers to questions on page 514.

11.3O The principal hardness-causing ions in water are calcium and magnesium.

11.3P Problems caused by hardness in water include (1) incrustations when water evaporates or scale when heated and (2) formation of precipitates when combined with soap.

Answers to questions on page 515.

11.3Q The jar test is used to (1) determine the correct coagulant dosage and (2) evaluate new coagulants or polymers.

11.3R Speeds used during the jar test are as follows:

1. 80 rpm for the first minute,
2. 20 rpm for the next 30 minutes, and
3. Stop stirring for the next 60 minutes.

These speeds should be adjusted if necessary to be similar to actual conditions in the water treatment plant.

Answers to questions on page 518.

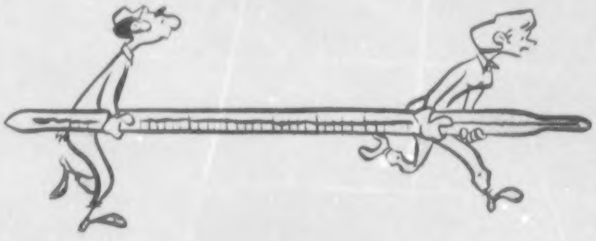
11.3S The pH of a water indicates the intensity of its basic or acid strength.

11.3T Precautions to be exercised when using a pH meter include:

1. Prepare fresh buffer solution weekly for calibration purposes;
2. Have pH meter, samples, and buffer solutions all near the same temperature;
3. Watch for erratic results arising from faulty operation of pH meter or fouling of electrodes with interfering matter;
4. The pH of water changes with temperature; and
5. If testing waters with a range of pH values, the "slope" of the pH meter may require adjusting.

Answers to questions on page 519.

11.3U Temperature readings are important because temperature influences chemical reaction rates, biological growth, dissolved gas concentrations, and water stability with respect to calcium carbonate. Also consumers are sensitive to the temperature of the water they drink.



11.3V The thermometer should remain immersed in the liquid while being read for accurate results. When removed from the liquid, the reading will change.

11.3W All thermometers should be calibrated against an accurate National Bureau of Standards thermometer because some (cheaper) thermometers are substantially inaccurate (off as much as 6°F or 3°C).

Answers to questions on page 520.

11.3X Turbidity in water can be caused by the presence of suspended matter such as silt, finely divided organic and inorganic matter, and microscopic organisms such as algae.

11.3Y Turbidity is measured by the nephelometric method.

OBJECTIVE TEST

Chapter 11. LABORATORY PROCEDURES

Please write your name and mark the correct answers on the answer sheet as directed at the end of Chapter 1. There may be more than one correct answer to the multiple choice questions.

TRUE OR FALSE

1. Composite samples should be used to measure the temperature of water.
   1. True
   2. False

2. When preparing a composite sample, the individual samples must be vigorously mixed before the portion for the composite is withdrawn and then the entire composite sample should be vigorously mixed.
   1. True
   2. False

3. The treatment plant superintendent is the only person responsible for lab safety.
   1. True
   2. False

4. Always wear safety glasses or goggles whenever any possible danger exists to your eyes.
   1. True
   2. False

5. Acids can injure you, but not bases (hydroxides).
   1. True
   2. False

6. A rubber bulb should be used to pipet raw water.
   1. True
   2. False

7. Acid may be added to water, but not the reverse.
   1. True
   2. False

8. The pH scale ranges from 0 to 13.
   1. True
   2. False

9. A water with a pH of 7 is basic.
   1. True
   2. False

10. End point titration may be based on a color change.
    1. True
    2. False

11. All bottles containing chemicals must be clearly labeled.
    1. True
    2. False

12. Carbonate hardness is the only type of hardness encountered in water supply systems.
    1. True
    2. False

13. The jar test is used to measure the corrosivity of water.
    1. True
    2. False

14. Jar tests duplicate exactly what is happening in a plant.
    1. True
    2. False

15. The Safe Drinking Water Act stipulates specific monitoring requirements for turbidity.
    1. True
    2. False

MULTIPLE CHOICE

16. Large errors in laboratory tests may be caused by
    1. Improper sampling.
    2. Lack of mixing during compositing.
    3. Large samples.
    4. Poor preservation.
    5. Poor quality product water.

17. The chemical symbol C stands for
    1. Calcium.
    2. Carbon.
    3. Chlorine.
    4. Copper.
    5. Cyanide.

18. The most accurate way to deliver accurate volumes of a sample is to use
    1. Beakers.
    2. Cylinders (graduated).
    3. Flasks.
    4. Graduates.
    5. Pipets.

19. Physical properties of water are described by
    1. Alkalinity.
    2. Chlorine.
    3. Color.
    4. Odor.
    5. Turbidity.

20. Poor data quality results from
    1. Calculation mistakes.
    2. Deteriorated reagents.
    3. Polluted raw waters.
    4. Poorly operating instruments.
    5. Sloppy laboratory techniques.

21. Explosive or flammable materials an operator may encounter include
    1. Acetone.
    2. Hydrochloric acid.
    3. Ethyl ether.
    4. Gasoline.
    5. Sodium hydroxide.

22. Water may be used to extinguish fires caused by
    1. Electrical equipment.
    2. Grease.
    3. Paint.
    4. Sodium.
    5. Textiles.

23. Water samples from a distribution system should be collected from a
    1. Drinking fountain.
    2. Fire hydrant.
    3. Leaky faucet.
    4. Sampling station.
    5. Tap surrounded by foliage.

24. A grab sample may be preferred over a composite sample when
    1. An overall description of the water for a 24-hour period is needed.
    2. The water quality indicators of interest will deteriorate with time.
    3. The water quality indicators of interest will not deteriorate with time.
    4. The water to be sampled does not flow on a continuous basis.
    5. The water's characteristics are relatively constant.

25. Manual water sampling equipment includes
    1. Dippers.
    2. Cross-section samplers.
    3. Glass jars.
    4. Hand-operated pumps.
    5. Weighted bottles.

26. Alkalinity in a natural water sample may include
    1. Bicarbonate alone.
    2. Bicarbonate and carbonate.
    3. Carbonate alone.
    4. Carbonate and hydroxide.
    5. Hydroxide alone.

27. Chlorine is used in water treatment to react with
    1. Coagulants.
    2. Iron.
    3. Floc.
    4. Pathogens.
    5. Taste- and odor-producing compounds.

28. The membrane filter method for the coliform test
    1. Diffuses nutrients down through the membrane to grow bacteria into colonies.
    2. Estimates MPN by the production of gas in inverted tubes or vials.
    3. Ideally should produce between 50 and 200 coliform colonies.
    4. Produces the same results as the multiple fermentation tube method.
    5. Uses a cellulose ester filter.

29. In addition to calcium and magnesium, hardness in water may be caused by
    1. Aluminum.
    2. Iron.
    3. Manganese.
    4. Potassium.
    5. Sodium.

30. Jar tests may be used to determine the optimum dosage of
    1. Alum.
    2. Chlorine.
    3. Flourine.
    4. Magnesium.
    5. Polymer.

Data to answer questions 31 and 32.

Results from MPN tests during one week were as follows:

Day	S	M	T	W	Th	F	S
MPN/100 m*L*	8	11	4	15	6	12	7

31. The mean MPN/100 m*L* from the data is
    1. 4
    2. 6
    3. 7
    4. 8
    5. 9

32. The median MPN/100 m*L* from the data is
    1. 4
    2. 6
    3. 7
    4. 8
    5. 9

End of Objective Test

APPENDIX

Final Examination

How to Solve Water Treatment Plant Arithmetic Problems

Water Abbreviations

Water Words

Subject Index

WATER TREATMENT PLANT OPERATION

VOLUME I

FINAL EXAMINATION

AND

SUGGESTED ANSWERS

FINAL EXAMINATION

This final examination was prepared *TO HELP YOU* review the material in the manual. The questions are divided into four types:

1. True-false,
2. Multiple choice,
3. Short answers, and
4. Problems.

To work this examination:

1. Write the answer to each question in your notebook,
2. After you have worked a group of questions (you decide how many), check your answers with the suggested answers at the end of this exam, and
3. If you missed a question and don't understand why, reread the material in the manual.

You may wish to use this examination for review purposes when preparing for civil service and certification examinations.

Since you have already completed this course, you do not have to send your answers to California State University, Sacramento.

True-False

1. Filtration settles out larger suspended particles.
    1. True
    2. False

2. A clear well provides chlorine contact time for disinfection.
    1. True
    2. False

3. An amber color in water could indicate the presence of humic substances which could later be converted into trihalomethanes.
    1. True
    2. False

4. Coliforms are used to measure specific disease-producing organisms in drinking water.
    1. True
    2. False

5. Corrosion problems can develop in water distribution systems if copper sulfate is used to control algae in water with a high TDS.
    1. True
    2. False

6. When a lake is frozen over, the temperature of the water withdrawn from lower elevations will be a few degrees colder than water withdrawn from close to the surface.
    1. True
    2. False

7. Detention times in flocculation basins increase when the flow increases.
    1. True
    2. False

8. Jar test reagents can be prepared using the actual chemical coagulants used to treat the water.
    1. True
    2. False

9. When water becomes colder, the detention time in a sedimentation basin should be reduced.
    1. True
    2. False

10. If the sludge being pumped from a sedimentation basin is too low in solids (soupy), the length of sludge removal pumping time should be increased.
    1. True
    2. False

11. Higher filter backwash rates are required at higher temperatures.
    1. True
    2. False

12. Shortened filter runs may result from filter-aid overdosing.
    1. True
    2. False

13. When the temperature of chlorine in a cylinder increases, the pressure of the chlorine gas in the cylinder will increase.
    1. True
    2. False

14. Breakpoint chlorination is the addition of chlorine to water until the chlorine demand is satisfied.
    1. True
    2. False

15. Very often when consumers complain about chlorine tastes in their drinking water, the chlorine dose has been excessive.
    1. True
    2. False

16. A tubercle is caused by the loss of metal from a pipe due to corrosion.
    1. True
    2. False

17. Finished water turbidity samples should be collected after the addition of lime for corrosion control to be sure that any turbidity will not interfere with final disinfection (postchlorination) in the clear well.
    1. True
    2. False

18. An important aspect of any taste and odor control program is prevention.
    1. True
    2. False

19. Aeration is best suited for treating taste problems.
    1. True
    2. False

20. The air supply for pneumatic instrumentation must be moist to prevent the controls from drying out.
    1. True
    2. False

21. Chlorine is a strong respiratory irritant.
    1. True
    2. False

22. Laboratory quality control tests provide the necessary information to monitor water treatment processes.
    1. True
    2. False

23. A bad sample can be useful if correct lab procedures are used.
    1. True
    2. False

24. Beakers are used to accurately measure volumes of chemicals when titrating.
    1. True
    2. False

25. Never pipet chemical reagent solutions or unknown water samples by mouth.
    1. True
    2. False

Multiple Choice

1. The specific types of treatment processes in a water treatment plant will depend on the type of
    1. Impurities in the raw water.
    2. Maintenance records available.
    3. Operator certification program.
    4. Owner.
    5. Water quality standards.

2. Health authorities encourage the use of reclaimed wastewater for
    1. Drinking water.
    2. Greenbelt irrigation.
    3. Industrial reuse.
    4. Landscape impoundments.
    5. Municipal swimming pools.

3. When conducting a sanitary survey, sources of waste discharges that must be investigated include
    1. Acid waters from mines.
    2. Agricultural drain waters.
    3. Industrial wastes.
    4. Oil field brines.
    5. Springs.

4. Which of the following water quality indicators significantly affect the efficiency of using copper sulfate as an algicide?
    1. Alkalinity
    2. Dissolved oxygen
    3. Iron and manganese
    4. Suspended solids
    5. Temperature

5. Water quality problems in reservoir water caused by substances released during decomposition include increased
    1. Algal populations.
    2. Color.
    3. Chlorine demand.
    4. TDS levels.
    5. Trihalomethanes following chlorination.

6. The major causes of faulty operation of gates and valves include
    1. Corroded parts.
    2. Excessive lubrication.
    3. Lack of use.
    4. Settlement of support structure.
    5. Vandalism.

7. When evaluating the results of jar tests, which of the following factors should be considered?
    1. Amount of floc formed
    2. Clarity of water above settled floc
    3. Clarity of water between floc particles
    4. Floc settling rate
    5. Rate of floc formation

8. Sudden changes in which of the following water quality indicators in the raw or filtered water are signals that the operator should immediately review the performance of the coagulation-flocculation process?
    1. Alkalinity
    2. Chlorine demand
    3. Coliforms
    4. Temperature
    5. Turbidity

9. Factors which affect particle settling in a sedimentation basin include
    1. Basin hydraulic characteristics.
    2. Density of particle.
    3. Density of water.
    4. pH of water.
    5. Size of particle.

10. Accumulated sludge must be removed periodically from the bottom of sedimentation basins to prevent
    1. Corrosion of sludge removal equipment.
    2. Formation of floc in sedimentation basin.
    3. Reduction of detention time.
    4. Resuspension of solids due to scouring.
    5. Sludge becoming septic.

11. Indications that the backwash rate is too low include
    1. Corrosion in the underdrain system.
    2. High initial head loss.
    3. Media material in the empty wash trough.
    4. Mounds on the media surface.
    5. Short filter runs.

12. The effectiveness of a polymer filter aid can be evaluated by observing
    1. Length of filter run.
    2. Quality of filter backwash water.
    3. Quantity of filter backwash water.
    4. Removal of floc by filter.
    5. Turbidity of the filter water.

13. One liter of liquid chlorine can evaporate and produce _____ liters of chlorine gas.
    1. 1
    2. 22.4
    3. 85
    4. 450
    5. 540

14. Factors influencing the effectiveness of disinfection by chlorination include
    1. Contact time.
    2. Organic matter.
    3. pH.
    4. Reducing agents.
    5. Turbidity.

15. Adverse effects of corrosion include
    1. Bad tastes in the water.
    2. Increases in pipe roughness.
    3. Increases in pump energy costs.
    4. Leaks in water mains.
    5. Reduced carrying capacity of water mains.

16. The calcium carbonate saturation pH of a water depends on which of the following factors?
    1. Alkalinity
    2. Calcium
    3. Iron
    4. TDS
    5. Temperature

17. Man-made causes of tastes and odors include
    1. Agricultural wastes.
    2. Chemical spills.
    3. Household plumbing.
    4. Industrial wastes.
    5. Urban runoff.

18. Chemical oxidation processes used to control tastes and odors include
    1. Chlorine.
    2. Hydrogen sulfide.
    3. Ozone.
    4. Potassium permanganate.
    5. Sulfur dioxide.

19. Primary drinking water regulations contain MCLs for
    1. Coliform bacteria.
    2. Color.
    3. Iron.
    4. Odor.
    5. Turbidity.

20. Tests that should be performed at least daily on raw water include
    1. Alkalinity.
    2. Chlorine residual.
    3. Jar test.
    4. Temperature.
    5. Turbidity.

21. When determining how much water to treat on a specific day, the amount treated as compared with the previous warm day should be decreased if
    1. A major sporting event is scheduled in town.
    2. A major water main has broken.
    3. The cannery in town is shutting down.
    4. The clear well storage level is low and decreasing.
    5. The temperature is decreasing.

22. Fires in electrical equipment should be extinguished by the use of
    1. Carbon dioxide.
    2. Dry chemicals.
    3. Foam.
    4. Vaporizing liquids.
    5. Water.

23. The greatest errors in laboratory tests are frequently caused by
    1. Improper sampling.
    2. Lack of enough mixing during testing.
    3. Poor sample preservation.
    4. Using improper laboratory techniques.
    5. Using old reagents.

24. Free residual chlorine refers to
    1. Chlorine (Cl_2).
    2. Dichloramine ($NHCl_2$).
    3. Hypochlorite ion (OCl^-).
    4. Hypochlorous acid (HOCl).
    5. Monochloramine (NH_2Cl).

25. Additional tests that can be performed to improve the interpretation of jar test results include
    1. Alkalinity.
    2. Chlorine demand.
    3. Filterability.
    4. pH.
    5. Turbidity.

Short Answers

1. What is the purpose of a water treatment plant?

2. What is the first priority of operating a water treatment plant?

3. What problems may be created in drinking waters after an algal bloom?

4. Where may waters containing tastes and odors be found in a reservoir?

5. What is the purpose of the coagulation and flocculation processes?

6. What should be done if there is a significant change in source water turbidity?

7. What are the purposes of the sedimentation process?

8. Why are adjustable V-notch weirs installed on the effluent launders in a sedimentation basin?

9. How can filter media be modified to solve filter problems caused by head loss and turbidity breakthrough?

10. How can you determine if filter backwash rates are too high?

11. Why should chlorinators be located in a separate room?

12. List the items that should be included in all safety programs.

13. How is the rate of gas flow in a chlorinator measured?

14. If liquid chlorine is escaping from a cylinder, what would you do?

15. Why should copper pipes not be connected to iron water pipes?

16. How can an operator determine if corrosion is a problem?

17. How can an Enslow column be used to determine if a water is corrosive?

18. Why must tastes and odors be controlled and eliminated from drinking water?

19. How can septic tank and leach field systems cause taste and odor problems in drinking water?

20. List the goals competent and responsible water treatment plant operators try to achieve.

21. Why should drinking water be low in turbidity?

22. Why are proper sampling procedures important when collecting water samples?

23. Samples should not be collected from water taps under what conditions?

24. What chemicals used in water treatment will cause changes in alkalinity?

25. Variations in the chlorine demand test are caused by what conditions?

Problems

1. Convert a flow of 350 GPM to MGD.

2. Convert a flow of 80 GPD to milliliters per minute.

3. Convert a flow of 200 m*L*/min to GPD.

4. Determine a chlorinator setting in pounds per 24 hours to treat a flow of 1.35 MGD with a chlorine dose of 2.8 mg/*L*.

5. The optimum liquid alum dose from jar tests is 11 mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the plant flow is 1.7 MGD. The liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of liquid solution.

6. A liquid alum tank is three feet in diameter. During a 24-hour period the level dropped 15 inches (15 in ÷ 12 in/ft = 1.25 ft) and the plant treated 3.8 million gallons of water. What is the actual alum dose in milligrams per liter? Liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of liquid solution.

7. The optimum liquid alum dose from the jar tests is 17 mg/*L*. Determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 2.9 MGD. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

8. Estimate the actual chemical feed in pounds per day from a dry chemical feeder. A pie tin weighs one-eighth of a pound (0.125 lbs) empty and 1.375 pounds after 12 minutes.

9. Determine the setting in percent stroke on a chemical feed pump. The pump delivering the water to be treated pumps at a flow of 450 GPM. The solution strength of the chemical being pumped is 2.5 percent and the desired dose is 3.0 mg/*L*. The chemical feed pump has a maximum capacity of 120 gallons per day at a setting of 100 percent capacity.

10. A reservoir has a surface area of 75,300 square feet and the desired dose of copper sulfate is five pounds per acre. How many pounds of copper sulfate will be needed?

11. The volume of a reservoir is estimated to be 9.8 million gallons. The desired chemical dose is 1.2 mg/*L*. Estimate the chemical dose in pounds.

12. A polymer feed pump delivers a flow of 150 gallons per day containing a six percent polymer solution with a specific gravity of 1.04. Estimate the polymer delivered in pounds per day.

13. Estimate the detention time in hours for two rectangular sedimentation basins. Each basin is 8-feet deep, 20-feet wide, and 40-feet long. The plant flow is 0.95 MGD.

14. A 14-foot wide by 20-foot long sand filter treats a flow of 0.8 MGD. Calculate the filtration rate in gallons per minute per square foot of filter surface area.

15. Determine the Unit Filter Run Volume (UFRV) for a filter 14-feet wide and 20-feet long if the volume of water filtered between backwash cycles is 1.4 million gallons.

16. During a filter run the total volume of water filtered was 2.6 million gallons. When the filter was backwashed, 97,400 gallons of water was used. Calculate the percent of the finished water used for backwashing.

17. Estimate the chlorine demand for a water in milligrams per liter if the chlorine dose is 2.8 mg/*L* and the chlorine residual is 0.5 mg/*L*.

18. Determine the setting on a chlorinator in pounds per day if the flow is 1.1 MGD and the chlorine dose is 2.8 mg/*L*.

19. Determine the setting on a hypochlorinator in gallons per day if the desired chlorine feed rate is 25 pounds per day and the hypochlorite solution contains two percent chlorine.

20. Estimate the desired strength (as a percent chlorine) of a hypochlorite solution which is pumped by a hypochlorinator that delivers 120 gallons per day. The water being treated requires a chlorine dose of 25 pounds of chlorine per day.

21. How many gallons of water must be added to twelve gallons of five percent hypochlorite solution to produce a 2.5 percent hypochlorite solution?

22. Estimate the average use of chlorine in pounds per day based on actual use of chlorine for one week as shown below.

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Chlorine Use, lbs	78	104	91	95	108	96	87

23. A water treatment plant has twelve 150-pound chlorine cylinders in storage. The plant uses an average of 78 pounds of chlorine per day. How many days' supply of chlorine is in storage?

24. Convert the temperature of water from 59° Fahrenheit to degrees Celsius.

25. Convert the temperature of water from 9° Celsius to degrees Fahrenheit.

26. Results from the MPN tests on raw water were as follows:

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
MPN/100 m*L*	21	40	79	23	34	253	41

Estimate the mean and median of the data in MPN/100 m*L*.

SUGGESTED ANSWERS FOR FINAL EXAMINATION

True-False

1. False Filtration filters out remaining suspended particles.
2. True A clear well provides chlorine contact time for disinfection.
3. True An amber color in water could indicate the presence of humic substances which could later be converted into trihalomethanes.
4. False Coliforms are used to measure the bacteriological quality for drinking water, but not specific disease-producing organisms.
5. True Corrosion problems can develop in water distribution systems if copper sulfate is used to control algae in water with a high TDS.
6. False When a lake is frozen over, the temperature of the water withdrawn from the lower elevations will be warmer than water withdrawn from close to the surface.
7. False Detention times in flocculation basins increase when the flow decreases.
8. True Jar test reagents can be prepared using the actual chemical coagulants used to treat the water.
9. False When water becomes colder, the detention time in a sedimentation basin should be increased.
10. False If the sludge being pumped from a sedimentation basin is too low in solids (soupy), the length of sludge removal pumping time should be decreased.
11. True Higher backwash rates are required at higher temperatures.
12. True Shortened filter runs may result from filter-aid overdosing.
13. True When the temperature of the chlorine in a cylinder increases, the pressure of the chlorine gas in the cylinder will increase.
14. True Breakpoint chlorination is the addition of chlorine to water until the chlorine demand is satisfied.
15. False Very often when consumers complain about chlorine tastes in their drinking water, the chlorine dose has been *INADEQUATE*.
16. True A tubercle is caused by the loss of metal from a pipe due to corrosion.
17. False Finished water turbidity samples should be collected after filtration, but before lime is added to determine the turbidity of the finished water.
18. True An important aspect of any taste and odor control program is prevention.

19. False Aeration is best suited for treating odor problems caused by volatile compounds.

20. False The air supply for pneumatic instrumentation must be dried to prevent condensation in equipment signal lines.

21. True Chlorine is a strong respiratory irritant.

22. True Laboratory quality control tests provide the necessary information to monitor water treatment processes.

23. False A bad sample is worthless even if perfect lab procedures are used.

24. False Burets are used to accurately measure volumes of chemicals when titrating.

25. True Never pipet chemical reagent solutions or unknown water samples by mouth.

Multiple Choice

1. 1, 5 The specific types of treatment processes in a water treatment plant will depend on the type of impurities in the raw water and water quality standards.

2. 2, 3, 4 Health authorities encourage the use of reclaimed wastewater for greenbelt irrigation, industrial reuse and landscape impoundments, but not for drinking water or municipal swimming pools.

3. 1, 2, 3, 4 When conducting a sanitary survey, sources of waste discharges that must be investigated include acid waters from mines, agricultural drain waters, industrial wastes, and oil field brines. Springs may be a source of drinking water, not wastes.

4. 1, 4, 5 Alkalinity, suspended solids, and water temperature are the three major water quality indicators that affect the efficiency of using copper sulfate as an algicide.

5. 1, 2, 3, 5 Water quality problems in reservoir water caused by substances released during decomposition include increased algal populations (from nutrients), color, chlorine demand and trihalomethanes following chlorination.

6. 1, 3, 4, 5 The major causes of faulty operation of gates and valves include corroded parts, lack of lubrication, lack of use, settlement of support structure, and vandalism.

7. 1, 2, 3, 4, 5 When evaluating the results of jar tests, consider amount of floc formed, clarity of water above settled floc and between floc particles, and rate of floc formation and settling.

8. 1, 2, 4, 5 Sudden changes in alkalinity, chlorine demand, temperature and turbidity of raw or filtered water are signals that the operator should immediately review the performance of the coagulation-flocculation process.

9. 1, 2, 3, 5 Factors which affect particle settling in a sedimentation basin include basin hydraulic charatceristics, density of particle, density of water, and size of particle.

10. 3, 4, 5 Accumulated sludge must be removed periodically from the bottom of sedimentation basins to prevent reduction of detention time, resuspension of solids due to scouring, and sludge becoming septic.

11. 2, 5 Indications that the backwash rate is too low include high initial head loss and short filter runs. Indications that the backwash rate is too high include media material in the empty wash trough and mounds on the media surface.

12. 1, 4, 5 The effectiveness of a polymer filter aid can be evaluated by observing the length of filter run, removal of floc by filter, and turbidity of filtered water.

13. 4 One liter of liquid chlorine can evaporate and produce *450* liters of chlorine gas.

14. 1, 2, 3, 4, 5 Contact time, organic matter, pH, reducing agents and turbidity all influence the effectiveness of disinfection by chlorination.

15. 1, 2, 3, 4, 5 Adverse effects due to corrosion include bad tastes in water, increases in pipe roughness, increases in pump energy costs, leaks in water mains, and reduced carrying capacity of water mains.

16. 1, 2, 4, 5 The calcium carbonate saturation pH of a water depends on the alkalinity, calcium, TDS and temperature.

17. 1, 2, 3, 4, 5 Man-made causes of tastes and odor include agricultural wastes, chemical spills, household plumbing, industrial wastes, and urban runoff.

18. 1, 3, 4 Chemical oxidation processes used to control tastes and odors include chlorine, ozone and potassium permanganate.

19. 1, 5 Primary drinking water regulations contain MCLs for coliform bacteria and turbidity; secondary regulations contain MCLs for color, iron and odor.

20. 1, 3, 4, 5 Tests that should be performed at least daily on raw water include alkalinity, jar test, temperature, and turbidity. Chlorine residual should be performed on the finished water.

21. 3, 5 The amount of water treated could be *DECREASED* if the cannery is shutting down and the temperature is decreasing. The amount treated should be *INCREASED* if a major sporting event is scheduled, a major water main has broken, and the clear well storage level is low and decreasing.

22. 1, 2, 4 Fires in electrical equipment should be extinguished by the use of carbon dioxide, dry chemicals or vaporizing liquids.

23. 1, 2, 3 The greatest errors in laboratory tests are frequently caused by improper sampling, lack of enough mixing during testing and poor sample preservation.

24. 1, 3, 4 Free residual chlorine refers to chlorine (Cl_2), hypochlorite ion (OCl^-), and hypochlorous acid (HOCl). Monochloramine (NH_2Cl) and dichloramine ($NHCl_2$) are combined chlorine.

25. 1, 3, 4, 5 Additional tests that can be performed to improve the interpretation of jar test results include alkalinity, filterability, pH and turbidity.

Short Answers

1. The purpose of a water treatment plant is to produce safe and pleasant drinking water. This water must be free of disease-causing organisms and toxic substances. Also the water should not have a disagreeable taste, odor or appearance.

2. The first priority for operating a water treatment plant is the production of a safe drinking water, one that is free of harmful bacteria and toxic materials.

3. After an algal bloom drinking water may develop tastes and odors, colors, and higher levels of chlorine demand. Also, high trihalomethane levels may occur following free residual chlorination.

4. Tastes and odors may be found in the upper layer of a thermally stratified reservoir, throughout a reservoir during periods of overturn, and throughout deeper waters when a reservoir is frozen over.

5. The purpose of coagulation and flocculation is to remove particulate impurities and color from the water being treated.

6. Significant changes in source water turbidity levels, either increases or decreases, generally require that the operator verify the effectiveness of the coagulant chemicals and dosages being applied at the flash mixer.

7. The purposes of the sedimentation process are to remove suspended solids (particles) that are denser (heavier) than the water to reduce the load on the filters.

8. Adjustable V-notch weirs are installed on the effluent launders in a sedimentation basin to control the water level and to prevent short-circuiting.

9. If the limiting head loss in a filter is frequently a problem and turbidity breakthrough rarely occurs, then a larger media size may be considered. If turbidity breakthrough is frequently a problem and limiting head loss is rarely encountered, then a smaller media size may be considered. If both head loss and turbidity breakthrough are constantly a problem, a deeper filter bed with a larger media size should be considered. You must realize that increasing the media depth is not always possible without modification of the filter box or tank.

10. To determine if filter backwash rates are too high, place a burlap bag on the backwash discharge line and examine what is caught in the bag. You could also observe how much media material remains in the empty wash trough or recovery basin when backwashing is completed.

11. Chlorinators should be in a separate room because chlorine gas leaks can damage equipment and are hazardous to operators.

12. Items that should be in all safety programs include:
    1. Establishment of a formal safety program,
    2. Written rules,
    3. Periodic hands-on training using safety equipment,
    4. Establishment of emergency procedures for chlorine leaks and first aid,
    5. Establishment of a maintenance and calibration program for safety devices and equipment, and
    6. Providing police and fire departments with tours of facilities to locate hazardous areas and provide chlorine safety information.

13. The rate of gas flow in a chlorinator is measured by the use of a rotameter.

14. If chlorine is escaping from a cylinder as a liquid, turn the cylinder so that the leak is on top and the chlorine will escape as a gas.

15. Copper pipes should not be connected to iron water pipes because the iron pipe will corrode into the water if dissolved oxygen is present.

16. An operator can determine if corrosion is a problem by examining materials from the distribution system for signs of corrosion damage. Chemical tests on the water can be used to indicate the corrosiveness of a water. If the distribution system has an increasing number of leaks and the consumers are complaining about dirty or red water, these are the most common indicators of corrosion problems.

17. An Enslow column can be used to determine if a water is corrosive by passing a portion of the treated water through the column. If the pH of the water passing through the column increases, then the water is corrosive. Also if the alkalinity increases, then the water is corrosive.

18. Tastes and odors must be controlled and eliminated because consumers may switch to alternative supplies which may be hazardous to their health. Perhaps the most damaging effect of a taste and odor episode is the loss of public confidence in the water quality which may result in funding and public relations problems.

19. Septic tank and leach field systems can cause taste and odor problems in drinking water if they are located too close together, too close to sources of the water supply, the soils have inadequate percolation rates, installation is substandard, and maintenance is poor.

20. Competent and responsible water treatment plant operators try to achieve production of (1) a safe drinking water, (2) an aesthetically pleasing drinking water, and (3) drinking water at a reasonable cost.

21. Drinking water must be low in turbidity because waters with high turbidity levels are difficult to disinfect effectively.

22. Proper sampling procedures are important so a sample can be collected for analysis which is representative of the water being sampled.

23. Samples should not be collected from water taps surrounded by excessive foliage (leaves, flowers) or that are dirty, corroded or leaking.

24. Chemicals used in water treatment that will cause changes in alkalinity include alum, chlorine and lime.

25. Conditions that cause variation in the chlorine demand of water include (1) the amount of chlorine applied, (2) time of contact, (3) pH, (4) temperature, (5) organics, and (6) reducing agents.

Problems

1. Convert a flow of 350 GPM to MGD.

Known		Unknown
Flow, GPM	= 350 GPM	Flow, MGD

Convert the flow of 350 GPM to MGD.

$$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= \frac{(350\text{ GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

$$= 0.5\text{ MGD}$$

2. Convert a flow of 80 GPD to milliliters per minute.

Known		Unknown
Flow, GPD	= 80 GPD	Flow, m*L*/min

Convert flow from 80 GPD to milliliters per minute.

$$\text{Flow, m}L\text{/min} = \frac{(\text{Flow, GPD})(3.785\ L\text{/gal})(1000\text{ m}L/L)}{(24\text{ hr/day})(60\text{ min/hr})}$$

$$= \frac{(80\text{ gal/day})(3.785\ L\text{/gal})(1000\text{ m}L/L)}{(24\text{ hr/day})(60\text{ min/hr})}$$

$$= 210\text{ m}L\text{/min}$$

3. Convert a flow of 200 m*L*/min to GPD.

Known		Unknown
Flow, m*L*/min	= 200 m*L*/min	Flow, GPD

Convert 200 m*L*/min to GPD.

$$\text{Flow, GPD} = \frac{(\text{Flow, m}L\text{/min})(60\text{ min/hr})(24\text{ hr/day})}{(1000\text{ m}L/L)(3.785\ L\text{/gal})}$$

$$= \frac{(200\text{ m}L\text{/min})(60\text{ min/hr})(24\text{ hr/day})}{(1000\text{ m}L/L)(3.785\ L\text{/gal})}$$

$$= 76\text{ GPD}$$

4. Determine a chlorinator setting in pounds per 24 hours to treat a flow of 1.35 MGD with a chlorine dose of 2.8 mg/*L*.

Known		Unknown
Flow, MGD	= 1.35 MGD	Chlorinator Setting, lbs/24 hours
Chlorine Dose, mg/*L*	= 2.8 mg/*L*	

Determine the chlorinator setting in pounds per 24 hours or pounds per day.

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

$$= (1.35\text{ MGD})(2.8\text{ mg}/L)(8.34\text{ lbs/gal})$$

$$= 32\text{ lbs/day}$$

5. The optimum liquid alum dose from jar tests is 11 mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the plant flow is 1.7 MGD. The liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of liquid solution.

Known		Unknown
Alum Dose, mg/*L*	= 11 mg/*L*	Chemical Feeder Setting, m*L*/min
Flow, MGD	= 1.7 MGD	
Liquid Alum, mg/m*L*	= 642.3 mg/m*L*	

Calculate the liquid alum chemical feeder setting in milliliters per minute.

$$\text{Chemical Setting, m}L\text{/min} = \frac{(\text{Flow, MGD})(\text{Alum, Dose, mg}/L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\text{ hr/day})(60\text{ min/hr})(1\text{ Million})}$$

$$= \frac{(1.7\text{ MGD})(11\text{ mg}/L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(642.3\text{ mg/m}L)(24\text{ hr/day})(60\text{ min/hr})(1\text{ Million})}$$

$$= 77\text{ m}L\text{/min}$$

6. A liquid alum tank is three feet in diameter. During a 24-hour period the level dropped 15 inches (1.25 ft) and the plant treats 3.8 million gallons of water. What is the actual alum dose in milligrams per liter? Liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of liquid solution.

Known		Unknown
Diameter, ft	= 3 ft	Alum Dose, mg/*L*
Drop, ft/day	= 1.25 ft/day	
Flow, M Gal/day	= 3.8 M Gal/day	
Liquid Alum, mg/m*L*	= 642.3 mg/m*L*	

Solution No. 1

1. Calculate the volume of liquid alum used in gallons per day.

$$\text{Alum, GPD} = (0.785)(\text{Diameter, ft})^2(\text{Drop, ft/day})(7.48\text{ gal/cu ft})$$

$$= (0.785)(3\text{ ft})^2(1.25\text{ ft/day})(7.48\text{ gal/cu ft})$$

$$= 66\text{ GPD}$$

2. Convert the liquid alum from mg/m*L* to pounds per gallon.

$$\text{Liquid Alum, lbs/gal} = \frac{(\text{Liquid Alum, mg/m}L)(1000\text{ m}L/L)(3.785\ L\text{/gal})}{(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= \frac{(642.3\text{ mg/m}L)(1000\text{ m}L/L)(3.785\ L\text{/gal})}{(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= 5.35\text{ lbs/gal}$$

3. Calculate the alum feed in pounds per day.

$$\text{Alum Feed, lbs/day} = (\text{Alum, gal/day})(\text{Liquid Alum, lbs/gal})$$

$$= (66\text{ GPD})(5.35\text{ lbs/gal})$$

$$= 353\text{ lbs/day}$$

4. Calculate the alum dose in milligrams per liter.

$$\text{Alum Dose, mg}/L = \frac{\text{Alum Feed, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{353\text{ lbs/day}}{(3.8\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 11\text{ mg}/L$$

Solution No. 2

1. Calculate the volume of alum used in liters per day.

$$\text{Alum, }L\text{/day} = (0.785)(\text{Diameter, ft})^2(\text{Drop, ft/day})(7.48\text{ gal/cu ft})(3.785\ L\text{/gal})$$

$$= (0.785)(3\text{ ft})^2(1.25\text{ ft/day})(7.48\text{ gal/cu ft})(3.785\ L\text{/gal})$$

$$= 250\ L\text{/day}$$

2. Calculate the million milligrams of alum used.

$$\text{Alum Feed, M mg/day} = \frac{(\text{Alum, }L\text{/day})(\text{Liquid Alum, mg/m}L)(1000\text{ m}L/L)(1\text{ Million})}{1{,}000{,}000}$$

$$= \frac{(250\ L\text{/day})(642.3\text{ mg/m}L)(1000\text{ m}L/L)(1\text{ Million})}{(1{,}000{,}000)}$$

$$= 160.575\text{ M mg/day}$$

3. Convert the flow from MGD to million liters per day.

$$\text{Flow M }L\text{/day} = (\text{Flow, MGD})(3.785\ L\text{/gal})$$

$$= (3.8\text{ MGD})(3.785\ L\text{/gal})$$

$$= 14.383\text{ M }L\text{/day}$$

4. Calculate the alum dose in milligrams per liter.

$$\text{Dose, mg/}L = \frac{\text{Alum Feed, M mg/day}}{\text{FLow, M }L\text{/day}}$$

$$= \frac{160.575\text{ M mg/day}}{14.383\text{ M }L\text{/day}}$$

$$= 11\text{ mg/}L$$

7. The optimum liquid alum dose from the jar tests is 17 mg/L. Determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 2.9 MGD. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

Known		Unknown
Alum Dose, mg/L	= 17 mg/L	Chemical Feeder Setting, GPD
Flow, MGD	= 2.9 MGD	
Liquid Alum, lbs/gal	= 5.36 lbs/gal	

Calculate the liquid alum chemical feeder setting in gallons per day

$$\text{Chemical Feeder Setting, GPD} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg/}L)(8.34\text{ lbs/gal})}{\text{Liquid Alum, lbs/gal}}$$

$$= \frac{(2.9\text{ MGD})(17\text{ mg/}L)(8.34\text{ lbs/gal})}{5.36\text{ lbs/gal}}$$

$$= 77\text{ GPD}$$

8. Estimate the actual chemical feed in pounds per day from a dry chemical feeder. A pie tin weighs one-eighth of a pound (0.125 lbs) empty and 1.375 pounds after 12 minutes.

Known		Unknown
Empty Tins, lbs	= 0.125 lbs	Chemical Feed, lbs/day
Full Tin, lbs	= 1.375 lbs	
Time, min	= 12 min	

Determine the chemical feed in pounds of chemical per day.

$$\text{Chemical Feed, lbs/day} = \frac{\text{Chemical Applied, lbs}}{\text{Length of Application, day}}$$

$$= \frac{(1.375\text{ lbs} - 0.125\text{ lbs})(60\text{ min/h})(24\text{ hr/day})}{12\text{ min}}$$

$$= 150\text{ lbs/day}$$

9. Determine the setting in percent stroke on a chemical feed pump. The pump delivering the water to be treated pumps at a flow of 450 GPM. The solution strength of the chemical being pumped is 2.5 percent and the desired dose is 3.0 mg/L. The chemical feed pump has a maximum capacity of 120 gallons per day at a setting of 100 percent capacity.

Known		Unknown
Pump Flow, GPM	= 450 GPM	Setting, % Stroke
Solution Strength, %	= 2.5%	
Feed Pump, GPD (100% stroke)	= 120 GPD	
Chemical Dose, mg/L	= 3.0 mg/L	

1. Convert the pump flow from GPM to MGD.

$$\text{Pump Flow, MGD} = (\text{Pump Flow, GPM})(60\text{ min/hr})(24\text{ hr/day})$$

$$= (450\text{ GPM})(60\text{ min/hr})(24\text{ hr/day})$$

$$= 648{,}000\text{ GPD}$$

$$= 0.648\text{ MGD}$$

2. Change the chemical solution strength from a percent to pounds of chemical per gallon of solution.

$$\text{Chemical Solution, lbs/gal} = \frac{2.5\text{ lbs chemical}}{100\text{ lbs of chemical and water}}$$

$$= \frac{(2.5\text{ lbs chemical})(8.34\text{ lbs/gal})}{100\text{ lbs}}$$

$$= 0.21\text{ lbs chemical/gal solution}$$

3. Calculate the chemical feed in pounds per day for a chemical dose of 3.0 mg/L.

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg/}L)(8.34\text{ lbs/gal})$$

$$= (0.648\text{ MGD})(3.0\text{ mg/}L)(8.34\text{ lbs/gal})$$

$$= 16.2\text{ lbs/day}$$

4. Determine the desired flow from the chemical feed pump in gallons per day.

$$\text{Feed Pump, GPD} = \frac{\text{Chemical Feed, lbs/day}}{\text{Chemical Solution, lbs/gal}}$$

$$= \frac{16.2\text{ lbs/day}}{0.21\text{ lbs/gal}}$$

$$= 77\text{ GPD}$$

5. Determine the setting on the chemical feed pump as a percent of the pump stroke.

$$\text{Setting, \%} = \frac{(\text{Desired Feed Pump, GPD})(100\%)}{\text{Maximum Feed Pump, GPD}}$$

$$= \frac{(77\text{ GPD})(100\%)}{120\text{ GPD}}$$

$$= 64\%$$

10. A reservoir has a surface area of 75,300 square feet and the desired dose of copper sulfate is five pounds per acre. How many pounds of copper sulfate will be needed?

Known		Unknown
Surface Area, sq ft	= 75,300 sq ft	Copper Sulfate, lbs
Dose, lbs/ac	= 5 lbs/ac	

1. Convert the surface area from square feet to acres.

$$\text{Surface Area, ac} = \frac{\text{Surface Area, sq ft}}{43{,}560\text{ sq ft/ac}}$$

$$= \frac{75{,}300\text{ sq ft}}{43{,}560\text{ sq ft/ac}}$$

$$= 1.73\text{ ac}$$

2. Calculate the pounds of copper sulfate needed.

$$\text{Copper Sulfate, lbs} = (\text{Surface Area, ac})(\text{Dose, lbs/ac})$$

$$= (1.73\text{ ac})(5\text{ lbs/ac})$$

$$= 8.65\text{ lbs}$$

11. The volume of a reservoir is estimated to be 9.8 million gallons. The desired chemical dose is 1.2 mg/*L*. Estimate the chemical dose in pounds.

Known	**Unknown**
Reservoir Vol, MG = 9.8 MG	Chemical Dose, lbs
Chemical Dose, mg/*L* = 1.2 mg/*L*	

Estimate the chemical dose in pounds.

$$\text{Chemical Dose, lbs} = (\text{Volume, MG})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

$$= (9.8\text{ MG})(1.2\text{ mg}/L)(8.34\text{ lbs/gal})$$

$$= 98\text{ lbs}$$

12. A polymer feed pump delivers a flow of 150 gallons per day containing a six percent polymer solution with a specific gravity of 1.04. Estimate the polymer delivered in pounds per day.

Known	**Unknown**
Pump Flow, GPD = 150 GPD	Polymer, lbs/day
Polymer, % = 6%	
Specific Gravity = 1.04	

Estimate the polymer delivered in pounds per day.

$$\text{Polymer, lbs/day} = \frac{(\text{Polymer Solution, gal/day})(8.34\text{ lbs/gal})(\text{Polymer, \%})(\text{Sp Gr})}{100\%}$$

$$= \frac{(150\text{ gal/day})(8.34\text{ lbs/gal})(6\%)(1.04)}{100\%}$$

$$= 78\text{ lbs/day}$$

13. Estimate the detention time in hours for two rectangular sedimentation basins. Each basin is 8-feet deep, 10-feet wide, and 20-feet long. The plant flow is 0.30 MGD.

Known	**Unknown**
Depth, ft = 8 ft	Detention Time, hr
Width, ft = 10 ft	
Length, ft = 20 ft	
Flow, GPD = 300,000 GPD	
Two Basins	

1. Calculate the total volume of the sedimentation basins in cubic feet.

$$\text{Volume, cu ft} = (\text{Depth, ft})(\text{Width, ft})(\text{Length, ft})(2\text{ Basins})$$

$$= (8\text{ ft})(10\text{ ft})(20\text{ ft})(2\text{ Basins})$$

$$= 3200\text{ cu ft}$$

2. Estimate the detention time of the sedimentation basin in hours.

$$\text{Detention Time, hr} = \frac{(\text{Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{(3200\text{ cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{300{,}000\text{ gal/day}}$$

$$= 1.9\text{ hr}$$

14. A 14-foot wide by 20-foot long sand filter treats a flow of 0.8 MGD. Calculate the filtration rate in gallons per minute per square foot of filter surface area.

Known	**Unknown**
Width, ft = 14 ft	Filtration Rate, GPM/sq ft
Length, ft = 20 ft	
Flow, MGD = 0.8 MGD	

1. Convert the flow from MGD to GPM.

$$\text{Flow, GPM} = \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}$$

$$= \frac{(0.8\text{ MGD})(1{,}000{,}000)}{(1\text{ Million})(24\text{ hr/day})(60\text{ min/hr})}$$

$$= 556\text{ GPM}$$

2. Calculate the filtration rate in gallons per minute per square foot of filter surface area.

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$= \frac{556\text{ GPM}}{(14\text{ ft})(20\text{ ft})}$$

$$= 2.0\text{ GPM/sq ft}$$

15. Determine the Unit Filter Run Volume (UFRV) for a filter 14-feet wide and 20-feet long if the volume of water filtered between backwash cycles is 1.4 million gallons.

Known	**Unknown**
Width, ft = 14 ft	UFRV, gal/sq ft
Length, ft = 24 ft	
Volume Filtered, gal = 1,400,000	

Calculate the Unit Filter Run Volume in gallons per square foot of filter surface area.

$$\text{UFRV, gal/sq ft} = \frac{\text{Volume Filtered, gal}}{\text{Filter Surface Area, sq ft}}$$

$$= \frac{1{,}400{,}000\text{ gal}}{(14\text{ ft})(24\text{ ft})}$$

$$= 4170\text{ gal/sq ft}$$

16. During a filter run the total volume of water filtered was 2.6 million gallons. When the filter was backwashed, 97,400 gallons of water was used. Calculate the percent of the finished water used for backwashing.

Known	**Unknown**
Water Filtered, gal = 2,600,000 gal	Backwash, %
Backwash Water, gal = 97,400 gal	

Calculate the percent of water used for backwashing.

$$\text{Backwash, \%} = \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}$$

$$= \frac{(97{,}400\ \text{gal})(100\%)}{2{,}600{,}000\ \text{gal}}$$

$$= 3.7\%$$

17. Estimate the chlorine demand for a water in milligrams per liter if the chlorine dose is 2.8 mg/*L* and the chlorine residual is 0.5 mg/*L*.

Known	Unknown
Chlorine Dose, mg/*L* = 2.8 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L* = 0.5 mg/*L*	

Estimate the chlorine demand of the water in milligrams per liter.

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L$$

$$= 2.8\ \text{mg}/L - 0.5\ \text{mg}/L$$

$$= 2.3\ \text{mg}/L$$

18. Determine the setting on a chlorinator in pounds per day if the flow is 1.1 MGD and the chlorine dose is 2.8 mg/*L*.

Known	Unknown
Flow, MGD = 1.1 MGD	Chlorine Feed, lbs/day
Dose, mg/*L* = 2.8 mg/*L*	

Determine the chlorinator setting in pounds per day.

$$\text{Chlorine Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (1.1\ \text{MGD})(2.8\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 25.7\ \text{lbs/day}$$

19. Determine the setting on a hypochlorinator in gallons per day if the desired chlorine feed rate is 25 pounds per day and the hypochlorite solution contains two percent chlorine.

Known	Unknown
Chlorine Feed, lbs/day = 25 lbs/day	Hypochlorinator, GPD
Hypochlorite, % = 2.0%	

Determine the hypochlorinator setting in gallons per day.

$$\text{Hypochlorinator, GPD} = \frac{(\text{Feed, lbs/day})(100\%)}{(8.34\ \text{lbs/gal})(\text{Hypochlorite, \%})}$$

$$= \frac{(25\ \text{lbs/day})(100\%)}{(8.34\ \text{lbs/gal})(2\%)}$$

$$= 150\ \text{GPD}$$

20. Estimate the desired strength (as a percent chlorine) of a hypochlorite solution which is pumped by a hypochlorinator that delivers 120 gallons per day. The water being treated requires a chlorine dose of 25 pounds of chlorine per day.

Known	Unknown
Hypochlorinator Flow, GPD = 120 GPD	Hypochlorinator, Strength, %
Chlorine Required, lbs/day = 25 lbs/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, GPD})(8.34\ \text{lbs/gal})}$$

$$= \frac{(25\ \text{lbs/day})(100\%)}{(120\ \text{GPD})(8.34\ \text{lbs/gal})}$$

$$= 2.5\%$$

21. How many gallons of water must be added to twelve gallons of five percent hypochlorite solution to produce a 2.5 percent hypochlorite solution?

Known	Unknown
Hypochlorite, gal = 12 gal	Water Added, gal
Desired Hypo, % = 2.5%	
Actual Hypo, % = 5.0%	

Calculate the gallons of water that must be added to produce a 2.5 percent hypochlorite solution.

$$\text{Water Added, gal} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(12\ \text{gal})(5\%) - (12\ \text{gal})(2.5\%)}{2.5\%}$$

$$= \frac{60 - 30}{2.5}$$

$$= 12\ \text{gallons}$$

22. Estimate the average use of chlorine in pounds per day based on actual use of chlorine for one week as shown below.

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Chlorine Use, lbs/day	78	104	91	95	108	96	87

Known	Unknown
Chlorine Use, lbs/day	Average Chlorine Use, lbs/day

Estimate the average chlorine use in pounds of chlorine per day.

$$\text{Average Chlorine Use, lbs/day} = \frac{\text{Sum of Chlorine Used Each Day, lbs}}{\text{Total Time, days}}$$

$$= \frac{78\ \text{lbs} + 104\ \text{lbs} + 91\ \text{lbs} + 95\ \text{lbs} + 108\ \text{lbs} + 96\ \text{lbs} + 87\ \text{lbs}}{7\ \text{days}}$$

$$= \frac{659\ \text{lbs}}{7\ \text{days}}$$

$$= 94\ \text{lbs/day}$$

23. A water treatment plant has twelve 150-pound chlorine cylinders in storage. The plant uses an average of 78 pounds of chlorine per day. How many days' supply of chlorine is in storage?

Known	Unknown
Chlorine Cylinders = 12 cylinders	Supply of Chlorine, days
Cylinder Wt, lbs/cyl = 150 lbs/cyl	
Ave Use, lbs/day = 78 lbs/day	

Calculate the available supply of chlorine in storage in days.

$$\text{Supply of Chlorine, days} = \frac{(\text{Cylinder Wt, lbs/cyl})(\text{No. of cylinders})}{\text{Ave Use, lbs/day}}$$

$$= \frac{(150\ \text{lbs/cyl})(12\ \text{cylinders})}{78\ \text{lbs/day}}$$

$$= 23\ \text{days}$$

24. Convert the temperature of water from 59° Fahrenheit to degrees Celsius.

Known	Unknown
Temp, °F = 59°F	Temp, °C

Change 59°F to degrees Celsius.

$$\text{Temperature, °C} = \frac{5(°F - 32°F)}{9}$$

$$= \frac{5(59°F - 32°F)}{9}$$

$$= 15°C$$

25. Convert the temperature of water from 9° Celsius to degrees Fahrenheit.

Known	Unknown
Temp, °C = 9°C	Temp, °F

Change 9°C to degrees Fahrenheit.

$$\text{Temperature, °F} = \frac{9(°C)}{5} + 32°F$$

$$= \frac{9(9°C)}{5} + 32°F$$

$$= 48°F$$

26. Results from the MPN tests on raw water were as follows:

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
MPN/100 m*L*	21	40	79	23	34	253	41

Estimate the mean and median of the data in MPN/100 m*L*.

1. Calculate the mean.

$$\text{Mean, MPN/100 m}L = \frac{\text{Sum of All MPNs}}{\text{Number of MPNs}}$$

$$= \frac{21 + 40 + 79 + 23 + 34 + 253 + 41}{7}$$

$$= \frac{491}{7}$$

$$= 70 \text{ MPN/100 m}L$$

2. Determine the median. Rearrange the data in ascending (increasing) order and select the middle value (three will be smaller and three will be larger in this example).

Order	1	2	3	4	5	6	7
MPN/100 m*L*	21	23	34	40	41	79	253

Median, MPN/100 m*L* = Middle value of a group of data

= 40 MPN/100 m*L*

APPENDIX

HOW TO SOLVE WATER TREATMENT PLANT ARITHMETIC PROBLEMS

(VOLUME I)

by

Ken Kerri

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OBJECTIVES

HOW TO SOLVE WATER TREATMENT PLANT ARITHMETIC PROBLEMS

After completion of this Appendix, you should be able to do the following:

1. Add, subtract, multiply and divide,
2. List from memory basic converson factors and formulas, and
3. Solve water treatment plant arithmetic problems.

APPENDIX. HOW TO SOLVE WATER TREATMENT PLANT ARITHMETIC PROBLEMS

A.0 HOW TO STUDY THIS APPENDIX

This appendix may be worked early in your training program to help you gain the greatest benefit from your efforts. Whether to start this appendix early or wait until later is your decision. The chapters in this manual were written in a manner requiring very little background in arithmetic. You may wish to concentrate your efforts on the chapters and refer to this appendix when you need help. Some operators prefer to complete this appendix early so they will not have to worry about how to do the arithmetic when they are studying the chapters. You may try to work this appendix early or refer to it while studying the other chapters.

The intent of this appendix is to provide you with a quick review of the addition, subtraction, multiplication and division needed to work the arithmetic problems in this manual. This appendix is not intended to be a math textbook. There are no fractions because you don't need fractions to work the problems in this manual. Some operators will be able to skip over the review of addition, subtraction, multiplication and division. Others may need more help in these areas. If you need help in solving problems, read Section A.9, "Steps in Solving Problems." Basic arithmetic textbooks are available at every local library or bookstore and should be referred to if needed. Most instructional or operating manuals for pocket electronic calculators contain sufficient information on how to add, subtract, multiply, and divide.

After you have worked a problem involving your job, you should check your calculations, examine your answer to see if it appears reasonable, and if possible have another operator check your work before making any decisions or changes.

A.1 BASIC ARITHMETIC

In this Section we are going to provide you with basic arithmetic problems involving addition, subtraction, multiplication and division. You may work the problems "by hand" if you wish, but we recommend you use an electronic pocket calculator. The operating or instructional manual for your calculator should outline the step-by-step procedures to follow. All calculators use similar procedures, but most of them are slightly different from others.

We will start with very basic, simple problems. Try working the problems and then comparing your answers with the given answers. If you can work these problems, you should be able to work the more difficult problems in the text of this training manual by using the same procedures.

A.10 Addition

$$\begin{array}{r} 2 \\ 3 \\ \hline 5 \end{array} \qquad \begin{array}{r} 6.2 \\ 8.5 \\ \hline 14. \end{array} \qquad \begin{array}{r} 16.7 \\ 38.9 \\ \hline 55.6 \end{array} \qquad \begin{array}{r} 6.12 \\ 38.39 \\ \hline 44.51 \end{array} \qquad \begin{array}{r} 43 \\ 39 \\ 34 \\ 38 \\ 39 \\ 37 \\ 29 \\ \hline 259 \end{array}$$

$$\begin{array}{r} 2.12 \\ 9.80 \\ \hline 11.92 \end{array} \qquad \begin{array}{r} 0.12 \\ 2.0 \\ \hline 2.12 \end{array} \qquad \begin{array}{r} 63 \\ 32 \\ \hline 95 \end{array} \qquad \begin{array}{r} 120 \\ 60 \\ \hline 180 \end{array}$$

$$\begin{array}{r} 4 \\ 7 \\ 2 \\ \hline 13 \end{array} \qquad \begin{array}{r} 23 \\ 79 \\ 31 \\ \hline 133 \end{array} \qquad \begin{array}{r} 16.2 \\ 43.5 \\ 67.8 \\ \hline 127.5 \end{array} \qquad \begin{array}{r} 45.98 \\ 28.09 \\ 114.00 \\ \hline 188.07 \end{array} \qquad \begin{array}{r} 70 \\ 50 \\ 40 \\ 80 \\ \hline 240 \end{array}$$

A.11 Subtraction

$$\begin{array}{r} 7 \\ -5 \\ \hline 2 \end{array} \qquad \begin{array}{r} 12 \\ -\ 3 \\ \hline 9 \end{array} \qquad \begin{array}{r} 25 \\ -\ 5 \\ \hline 20 \end{array} \qquad \begin{array}{r} 78 \\ -30 \\ \hline 48 \end{array} \qquad \begin{array}{r} 83 \\ -69 \\ \hline 14 \end{array}$$

$$\begin{array}{r} 61 \\ -37 \\ \hline 24 \end{array} \qquad \begin{array}{r} 485 \\ -296 \\ \hline 189 \end{array} \qquad \begin{array}{r} 4.3 \\ -0.8 \\ \hline 3.5 \end{array} \qquad \begin{array}{r} 3.5 \\ -0.7 \\ \hline 2.8 \end{array} \qquad \begin{array}{r} 123 \\ -109 \\ \hline -\ 14 \end{array}$$

$$\begin{array}{r} 8.6 \\ -8.22 \\ \hline 0.38 \end{array} \qquad \begin{array}{r} 11.92 \\ -\ 3.70 \\ \hline 8.22 \end{array} \qquad \begin{array}{r} 27.32 \\ -12.96 \\ \hline 14.36 \end{array} \qquad \begin{array}{r} 3.574 \\ -0.042 \\ \hline 3.532 \end{array} \qquad \begin{array}{r} 75.132 \\ -49.876 \\ \hline 25.256 \end{array}$$

A.12 Multiplication

(3)(2)[a] = 6 (4)(7) = 28
(10)(5) = 50 (10)(1.3) = 13
(2)(22.99) = 45.98 (6)(19.5) = 117
(16)(17.1) = 273.6 (50)(20,000) = 1,000,000
(40)(2.31) = 92.4 (80)(0.433) = 34.6

(40)(20)(6) = 4,800
(4,800)(7.48) = 35,904
(1.6)(2.3)(8.34) = 30.6912
(0.001)(200)(8.34) = 1.668
(0.785)(7.48)(60) = 352.308
(12,000)(500)(60)(24) = 8,640,000,000 or 8.64×10^9
(4)(1000)(1000)(454) = 1,816,000,000 or 1.816×10^9

NOTE: The term, $\times 10^9$, means that the number is multiplied by 10^9 or 1,000,000,000. Therefore $8.64 \times 10^9 = 8.64 \times 1,000,000,000 = 8,640,000,000$.

---

[a] (3)(2) is the same as 3 × 2 = 6.

A.13 Division

$$\frac{6}{3} = 2$$

$$\frac{50}{25} = 2$$

$$\frac{20}{7.1} = 2.8$$

$$\frac{1{,}000{,}000}{17.5} = 57{,}143$$

$$\frac{4{,}000{,}000}{74{,}880} = 53.4$$

$$\frac{80}{2.31} = 34.6$$

$$\frac{250}{17.1} = 14.6$$

$$\frac{48}{12} = 4$$

$$\frac{300}{20} = 15$$

$$\frac{11{,}400}{188} = 60.6$$

$$\frac{861{,}429}{30{,}000} = 28.7$$

$$\frac{1.67}{8.34} = 0.20$$

$$\frac{62}{454} = 0.137$$

$$\frac{4{,}000{,}000}{14.6} = 273{,}973$$

NOTE: When we divide ⅓ = 0.3333, we get a long row of 3s. Instead of the row of 3s, we "round-off" our answer so ⅓ = 0.33. For a discussion of rounding off numbers, see Section A.95, "Significant Figures."

A.14 Multiplication and Division

Many of the problems we work in the waterworks field involve both multiplication and division. Sometimes addition or subtraction is also involved. To work these types of problems:

1. Do all the addition and subtraction above and below the line,
2. Do all the multiplication above and below the line, and
3. Perform the division.

Instructions for your electronic calculator can provide you with the detailed procedures.

$$\frac{(3)(4)}{2} = 6$$

$$\frac{(2+3)(4)}{5} = 4$$

$$\frac{(7-2)(8)}{4} = 10$$

$$\frac{(9)(8)-(6)(6)}{3} = 12$$

$$\frac{(20)}{(0.85)(8.34)} = 2.82$$

$$\frac{(14)(2)}{(13.53-12.98)(8.34)} = 6.10$$

$$\frac{(13)(100)}{(120)(8.34)} = 1.3$$

$$\frac{861{,}429}{(500)(60)} = 28.7$$

$$\frac{64}{(8)(4)} = 2$$

$$\frac{(54)}{(4+2)(3)} = 3$$

$$\frac{48}{(8-3)(4)} = 2.4$$

$$\frac{(16)(6)}{(8)(7)-(4)(4)} = 2.4$$

$$\frac{30-27}{(1.6)(8.34)} = 0.22$$

$$\frac{(4)(1{,}000{,}000)}{74{,}880} = 53.4$$

$$\frac{(0.1)(60)(24)}{3} = 48$$

$$\frac{(12{,}000)(500)(60)(24)}{(4)(1000)(1000)(454)} = 4.76$$

$$\frac{12}{(0.432)(8.34)} = 3.3$$

$$\frac{(274{,}000)(24)}{200{,}000} = 32.88$$

A.15 Actual Problems

Let's look at the last four problems in the previous Section A.14, "Multiplication and Division," as they might be encountered by an operator.

1. To determine the actual chemical feed rate from an alum feeder, an operator collects the alum from the feeder in a bucket for three minutes. The alum in the bucket weighs 0.1 pounds.

Known		Unknown
Weight of Alum, lbs	= 0.1 lbs	Actual Alum Feed, lbs/day
Time, min	= 3 min	

Calculate the actual alum feed rate in pounds per day.

$$\begin{aligned}\text{Actual Alum Feed Rate, lbs/day} &= \frac{(\text{Alum Wt, lbs})(60\ \text{min/hr})(24\ \text{hr/day})}{\text{Time Alum Collected, min}}\\ &= \frac{(0.1\ \text{lbs})(60\ \text{min/hr})(24\ \text{hr/day})}{3\ \text{min}}\\ &= 48\ \text{lbs/day}\end{aligned}$$

2. A solution chemical feeder is calibrated by measuring the time to feed 500 milliliters of chemical solution. The test calibration run required four minutes. The chemical concentration in the solution is 12,000 mg/*L* or 1.2%. Determine the chemical feed in pounds per day.

Known		Unknown
Volume Pumped, m*L*	= 500 m*L*	Chemical Feed, lbs/day
Time Pumped, min	= 4 min	
Chemical Conc., mg/*L*	= 12,000 mg/*L*	

Estimate the chemical feed rate in pounds per day.

$$\begin{aligned}\text{Chemical Feed, lbs/day} &= \frac{(\text{Chem Conc, mg}/L)(\text{Vol Pumped, m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(\text{Time Pumped, min})(1000\ \text{m}L/L)(1000\ \text{mg/gm})(454\ \text{gm/lb})}\\ &= \frac{(12{,}000\ \text{mg}/L)(500\ \text{m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(4\ \text{min})(1000\ \text{m}L/L)(1000\ \text{mg/gm})(454\ \text{gm/lb})}\\ &= 4.76\ \text{lbs/day}\end{aligned}$$

3. A chlorinator is set to feed twelve pounds of chlorine per day to a flow of 300 gallons per minute (0.432 million gallons per day). What is the chlorine dose in milligrams per liter?

Known		Unknown
Chlorinator Feed, lbs/day	= 12 lbs/day	Chlorine Dose, mg/*L*
Flow, MGD	= 0.432 MGD	

Determine the chlorine dose in milligrams per liter.

$$\text{Chlorine Dose, mg}/L = \frac{\text{Chlorinator Feed Rate, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

$$= \frac{12\text{ lbs/day}}{(0.432\text{ MGD})(8.34\text{ lbs/gal})}$$

$$= 3.3\text{ mg}/L$$

4. Estimate the operating time of a water softening ion exchange unit before the unit needs regeneration. The unit can treat 274,000 gallons of water before the exchange capacity is exhausted. The average daily flow is 200,000 gallons per day.

Known		Unknown
Water Treated, gal	= 274,000 gal	Operating Time, hr
Ave Daily Flow, gal/day	= 200,000 gal/day	

Estimate the operating time of the ion exchange unit in hours.

$$\text{Operating Time, hr} = \frac{(\text{Water Treated, gal})(24\text{ hr/day})}{\text{Ave Daily Flow, gal/day}}$$

$$= \frac{(274{,}000\text{ gal})(24\text{ hr/day})}{200{,}000\text{ gal/day}}$$

$$= 32.9^{*}\text{ hours}$$

---

*We rounded off 32.88 hours to 32.9 hours.

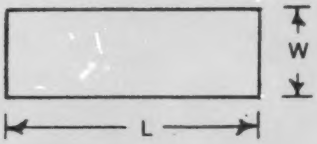
A.2 AREAS

A.20 Units

Areas are measured in two dimensions or in square units. In the English system of measurement the most common units are square inches, square feet, square yards, and square miles. In the metric system the units are square millimeters, square centimeters, square meters, and square kilometers.

A.21 Rectangle

The area of a rectangle is equal to its length (L) multiplied by its width (W).



A = L × W

Example: Find the area of a rectangle if the length is 5 feet and the width is 3.5 feet.

$$\text{Area, sq ft} = \text{Length, ft} \times \text{Width, ft}$$
$$= 5\text{ ft} \times 3.5\text{ ft}$$
$$= 17.5\text{ ft}^2$$
$$= 17.5\text{ sq ft}$$

Example: The surface area of a settling basin is 330 square feeet. One side measures 15 feet. How long is the other side?

$$A = L \times W$$

$$330\text{ sq ft} = L\text{ ft} \times 15\text{ ft}$$

$$\frac{L\text{ ft} \times 15\text{ ft}}{15\text{ ft}} = \frac{330\text{ ft}^2}{15\text{ ft}}$$ Divide both sides of equation by 15 ft.

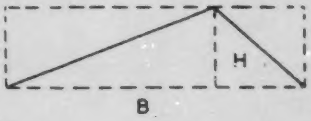
$$L\text{ ft} = \frac{330\text{ ft}^2}{15\text{ ft}}$$

$$= 22\text{ ft}$$

A.22 Triangle

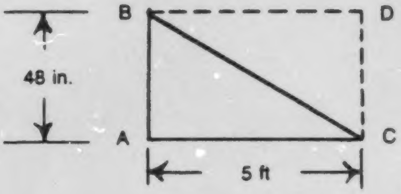
The area of a triangle is equal to one half the base multiplied by the height. This is true for any triangle.

A = ½ B × H



NOTE: The area of *ANY* triangle is equal to ½ the area of the rectangle that can be drawn around it. The area of the rectangle is B × H. The area of the triangle is ½ B × H.

Example: Find the area of triangle ABC.



The first step in the solution is to make all the units the same. In this case, it is easier to change inches to feet.

$$48\,\cancel{\text{in}} = 48\text{ in} \times \frac{1\text{ ft}}{12\,\cancel{\text{in}}} = \frac{48}{12}\text{ ft} = 4\text{ ft}$$

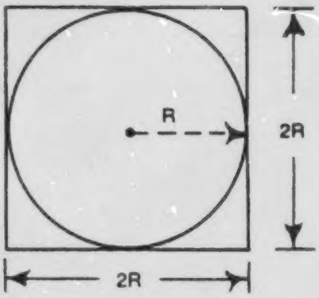
NOTE: All conversions should be calculated in the above manner. Since 1 ft/12 in is equal to unity, or one, multiplying by this factor changes the form of the answer but not its value.

$$\text{Area, sq ft} = ½\,(\text{Base, ft})(\text{Height, ft})$$
$$= ½ \times 5\text{ ft} \times 4\text{ ft}$$
$$= \frac{20}{2}\text{ ft}^2$$
$$= 10\text{ sq ft}$$

NOTE: Triangle ABC is one half the area of rectangle ABCD. The triangle is a special form called a *RIGHT TRIANGLE* since it contains a 90° angle at point A.

A.23 Circle

A square with sides of 2R can be drawn around a circle with a radius of R.



The area of the square is: $A = 2R \times 2R = 4R^2$.

It has been found that the area of any circle inscribed within a square is slightly more than ¾ of the area of the square. More precisely, the area of the preceding circle is:

$$A \text{ circle} = 3\frac{1}{7}R^2 = 3.14\,R^2$$

The formula for the area of a circle is usually written:

$$\boxed{A = \pi R^2}$$

The Greek letter π (pronounced pie) merely substitutes for the value 3.1416.

Since the diameter of any circle is equal to twice the radius, the formula for the area of a circle can be rewritten as follows:

$$A = \pi R^2 = \pi \times R \times R = \pi \times \frac{D}{2} \times \frac{D}{2} = \frac{\pi D^2}{4} = \frac{3.14}{4}\,D^2 = \boxed{0.785\,D^2}$$

The type of problem and the magnitude of the numbers in a problem will determine which of the two formulas will provide a simpler solution. All of these formulas will give the same results if you use the same number of digits to the right of the decimal point.

Example: What is the area of a circle with a diameter of 20 centimeters?

In this case, the formula using a radius is more convenient since it takes advantage of multiplying by 10.

$$\begin{aligned}\text{Area, sq cm} &= \pi\,(\text{R, cm})^2\\ &= 3.14 \times 10 \text{ cm} \times 10 \text{ cm}\\ &= 314 \text{ sq cm}\end{aligned}$$

Example: What is the area of a clarifier with a 50-foot radius?

In this case, the formula using diameter is more convenient.

$$\begin{aligned}\text{Area, sq ft} &= 0.785\,(\text{Diameter, ft})^2\\ &= 0.785 \times 100 \text{ ft} \times 100 \text{ ft}\\ &= 7850 \text{ sq ft}\end{aligned}$$

Occasionally the operator may be confronted with a problem giving the area and requesting the radius or diameter. This presents the special problem of finding the square root of the number.

Example: The surface area of a circular clarifier is approximately 5000 square feet. What is the diameter?

$A = 0.785\,D^2$, or

$\text{Area, sq ft} = 0.785\,(\text{Diameter, ft})^2$

$5000 \text{ sq ft} = 0.785\,D^2$ — To solve, substitute given values in equation.

$\dfrac{0.785\,D^2}{0.785} = \dfrac{5000 \text{ sq ft}}{0.785}$ — Divide both sides by 0.785 to find D^2

$$\begin{aligned}D^2 &= \frac{5000 \text{ sq ft}}{0.785}\\ &= 6369 \text{ sq ft. Therefore,}\end{aligned}$$

D = square root of 6369 sq ft, or

$\text{Diameter, ft} = \sqrt{6369 \text{ sq ft}}$.

Sometimes it is easier to use a trial and error method of finding square roots. Since 80 × 80 = 6400, we know the answer is close to 80 feet.

Try 79 × 79 = 6241

Try 79.5 × 79.5 = 6320.25

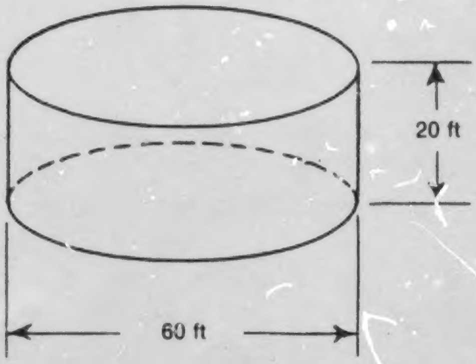
Try 79.8 × 79.8 = 6368.04

The diameter is 79.8 ft, or approximately 80 feet.

A.24 Cylinder

With the formulas presented thus far, it would be a simple matter to find the number of square feet in a room that was to be painted. The length of each wall would be added together and then multiplied by the height of the wall. This would give the surface area of the walls (minus any area for doors and windows). The ceiling area would be found by multiplying length times width and the result added to the wall area gives the total area.

The surface area of a circular cylinder, however, has not been discussed. If we wanted to know how many square feet of surface area are in a tank with a diameter of 60 feet and a height of 20 feet, we could start with the top and bottom.



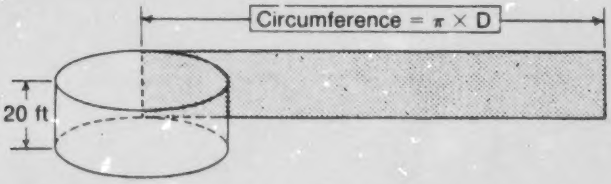
The area of the top and bottom ends are both $\pi \times R^2$

Area, sq ft $= 2$ ends $(\pi)(\text{Radius, ft})^2$

$= 2 \times \pi \times (30\text{ ft})^2$

$= 5652$ sq ft

The surface area of the wall must now be calculated. If we made a vertical cut in the wall and unrolled it, the straightened wall would be the same length as the circumference of the floor and ceiling.



This length has been found to always be $\pi \times D$. In the case of the tank, the length of the wall would be:

Length, ft $= (\pi)(\text{Diameter, ft})$

$= 3.14 \times 60$ ft

$= 188.4$ ft

Area would be:

A_w, sq ft $=$ Length, ft $\times$ Height, ft

$= 188.4\text{ ft} \times 20\text{ ft}$

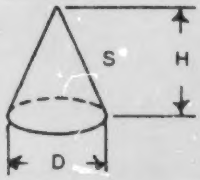
$= 3768$ sq ft

Outside Surface Area to Paint, sq ft $=$ Area of top and bottom, sq ft $+$ Area of wall, sq ft

$= 5652\text{ sq ft} + 3768\text{ sq ft}$

$= 9420$ sq ft

A container has inside and outside surfaces and you may need to paint both of them.



A.25 Cone

The lateral area of a cone is equal to ½ of the slant height (S) multiplied by the circumference of the base.

$$\boxed{A_L = \tfrac{1}{2} S \times \pi \times D = \pi \times S \times R}$$

In this case the slant height is not given, it may be calculated by:

$S = \sqrt{R^2 + H^2}$

Example: Find the entire outside area of a cone with a diameter of 30 inches and a height of 20 inches.

Slant Height, in $= \sqrt{(\text{Radius, in})^2 + (\text{Height, in})^2}$

$= \sqrt{(15\text{ in})^2 + (20\text{ in})^2}$

$= \sqrt{225\text{ in}^2 + 400\text{ in}^2}$

$= \sqrt{625\text{ in}^2}$

$= 25$ in

Area of Cone, sq in $= \pi$ (Slant Height, in)(Radius, in)

$= 3.14 \times 25\text{ in} \times 15\text{ in}$

$= 1177.5$ sq in

Since the entire area was asked for, the area of the base must be added.

Area, sq in $= 0.785\,(\text{Diameter, in})^2$

$= 0.785 \times 30\text{ in} \times 30\text{ in}$

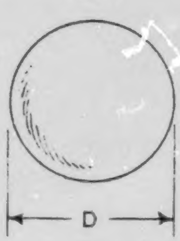
$= 706.5$ sq in

$=$ Area of Cone, sq in $+$ Area of Bottom, sq in

Total Area, sq in $= 1177.5\text{ sq. in} + 706.5\text{ sq in}$

$= 1884$ sq in

A.26 Sphere



The surface area of a sphere or ball is equal to π multiplied by the diameter squared.

$$\boxed{A_S = \pi D^2}$$

If the radius is used, the formula becomes:

$A_S = \pi D^2 = \pi \times 2R \times 2R = 4\pi R^2$

Example: What is the surface area of a sphere-shaped water tank 20 feet in diameter?

Area, sq ft $= \pi\,(\text{Diameter, ft})^2$

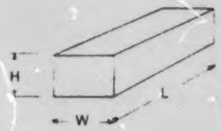
$= 3.14 \times 20\text{ ft} \times 20\text{ ft}$

$= 1256$ sq ft

A.3 VOLUMES

A.30 Rectangle

Volumes are measured in three dimensions or in cubic units. To calculate the volume of a rectangle, the area of the base is calculated in square units and then multiplied by the height. The formula then becomes:



$$\boxed{V = L \times W \times H}$$

Example: The length of a box is two feet, the width is 15 inches, and the height is 18 inches. Find its volume.

$$\text{Volume, cu ft} = \text{Length, ft} \times \text{Width, ft} \times \text{Height, ft}$$

$$= 2\ \text{ft} \times \frac{15\ \text{in}}{12\ \text{in/ft}} \times \frac{18\ \text{in}}{12\ \text{in/ft}}$$

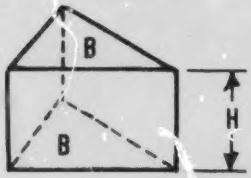
$$= 2\ \text{ft} \times 1.25\ \text{ft} \times 1.5\ \text{ft}$$

$$= 3.75\ \text{cu ft}$$

A.31 Prism

The same general rule that applies to the volume of a rectangle also applies to a prism.

$$\boxed{\text{Volume} = \text{Area of Base} \times \text{Height}}$$



Example: Find the volume of a prism with a base area of 10 square feet and a height of 5 feet. (Note that the base of a prism is triangular in shape)

$$\text{Volume, cu ft} = \text{Area of Base, sq ft} \times \text{Height, ft}$$

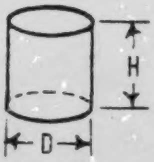
$$= 10\ \text{sq ft} \times 5\ \text{ft}$$

$$= 50\ \text{cu ft}$$

A.32 Cylinder

The volume of a cylinder is equal to the area of the base multiplied by the height.

$$\boxed{V = \pi R^2 \times H = 0.785\ D^2 \times H}$$



Example: A tank has a diameter of 100 feet and a depth of 12 feet. Find the volume.

$$\text{Volume, cu ft} = 0.785 \times (\text{Diameter, ft})^2 \times \text{Height, ft}$$

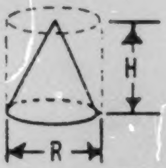
$$= 0.785 \times 100\ \text{ft} \times 100\ \text{ft} \times 12\ \text{ft}$$

$$= 94{,}200\ \text{cu ft}$$

A.33 Cone

The volume of a cone is equal to ⅓ the volume of a circular cylinder of the same height and diameter.

$$\boxed{V = \frac{\pi}{3} R^2 \times H}$$



Example: Calculate the additional volume in the cone portion of the tank in Section A.32 if the depth at the center of the tank is 16 ft. H = 16 ft − 12 ft.

$$\text{Volume, cu ft} = \frac{\pi}{3} \times (\text{Radius})^2 \times \text{Height, ft}$$

$$= \frac{\pi}{3} \times 50\ \text{ft} \times 50\ \text{ft} \times 4\ \text{ft}$$

$$= 10{,}500\ \text{cu ft}$$

A.34 Sphere

The volume of a sphere is equal to $\pi/6$ times the diameter cubed.

$$V = \frac{\pi}{6} \times D^3$$

Example: How much gas can be stored in a sphere with a diameter of 12 feet? (Assume atmospheric pressure.)

$$\text{Volume, cu ft} = \frac{\pi}{6} \times (\text{Diameter, ft})^3$$

$$= \frac{\pi}{\cancel{6}} \times \overset{2}{\cancel{12}}\ \text{ft} \times 12\ \text{ft} \times 12\ \text{ft}$$

$$= 904.32\ \text{cubic feet}$$

A.4 METRIC SYSTEM

The two most common systems of weights and measures are the English system and the Metric system. Of these two, the Metric system is more popular with most of the nations of the world. The reason for this is that the Metric system is based on a system of tens and is therefore easier to remember and easier to use than the English system. Even though the basic system in the United States is the English system, the scientific community uses the Metric system almost exclusively. Many organizations have urged, for good reason, that the United States switch to the Metric system. Today the Metric system is gradually becoming the standard system of measurement in the United States.

As the United States changes from the English to the Metric system, some confusion and controversy has developed. For example, which is the correct spelling of the following words:

1. Liter or litre?
2. Meter or metre?

The U.S. National Bureau of Standards, the Water Pollution Control Federation, and the American Water Works Association use litre and metre. The U.S. Government uses liter and meter and accepts no deviations. Some people argue that METRE should be used to measure LENGTH and that METER should be used to measure FLOW RATES (like a water or electric meter). Liter and Meter are used in this manual because this is most consistent with spelling in the United States.

One of the most frequent arguments heard against the U.S. switching to the Metric system was that the costs of switching manufacturing processes would be excessive. Pipe manufacturers have agreed upon the use of a "soft" metric conversion system during the conversion to the Metric system. Past practice in the U.S. has identified some types of pipe by external (outside) diameter while other types are classified by nominal (existing only in name, not real or actual) bore. This means that a six-inch pipe does not have a six-inch inside diameter. With the strict or "hard" metric system, a six-inch pipe would be a 152.4 mm (6 in × 25.4 mm/in) pipe. In the "soft" metric system a six-inch pipe is a 150 mm (6 in × 25 mm/in) pipe. Typical customary and "soft" metric pipe-size designations are shown below:

PIPE-SIZE DESIGNATIONS

Customary, in	2	4	6	8	10	12	15	18
"Soft" Metric, mm	50	100	150	200	250	300	375	450
Customary, in	24	30	36	42	48	60	72	84
"Soft" Metric, mm	600	750	900	1050	1200	1500	1800	2100

In order to study the Metric system, you must know the meanings of the terminology used. Following is a list of Greek and Latin prefixes used in the Metric system.

PREFIXES USED IN THE METRIC SYSTEM

Prefixes	Symbol	Meaning
Micro	μ	1/1 000 000 or 0.000 001
Milli	m	1/1000 or 0.001
Centi	c	1/100 or 0.01
Deci	d	1/10 or 0.1
Unit		1
Deka	da	10
Hecto	h	100
Kilo	k	1000
Mega	M	1 000 000

A.40 Measures of Length

The basic measure of length is the meter.

1 kilometer (km) = 1000 meters (m)
1 meter (m) = 100 centimeters (cm)
1 centimeter (cm) = 10 millimeters (mm)

Kilometers are usually used in place of miles, meters are used in place of feet and yards, centimeters are used in place of inches and millimeters are used for inches and fractions of an inch

LENGTH EQUIVALENTS

1 kilometer	= 0.621 mile	1 mile	= 1.64 kilometers
1 meter	= 3.28 feet	1 foot	= 0.305 meter
1 meter	= 39.37 inches	1 inch	= 0.0254 meter
1 centimeter	= 0.3937 inch	1 inch	= 2.54 centimeter
1 millimeter	= 0.0394 inch	1 inch	= 25.4 millimeters

NOTE: The above equivalents are reciprocals. If one equivalent is given, the reverse can be obtained by division. For instance, if one meter equals 3.28 feet, one foot equals 1/3.28 meter, or 0.305 meter.

A.41 Measures of Capacity or Volume

The basic measure of capacity in the Metric system is the liter. For measurement of large quantities the cubic meter is sometimes used.

1 kiloliter (k*L*) = 1000 liters (*L*) = 1 cu meter (m^3)

1 liter (*L*) = 1000 milliliters (m*L*)

Kiloliters, or cubic meters, are used to measure capacity of large storage tanks or reservoirs in place of cubic feet or gallons. Liters are used in place of gallons or quarts. Milliliters are used in place of quarts, pints, or ounces.

CAPACITY EQUIVALENTS

1 kiloliter	= 264.2 gallons	1 gallon	= 0.003785 kiloliter
1 liter	= 1.057 quarts	1 quart	= 0.946 liter
1 liter	= 0.2642 gallons	1 gallon	= 3.785 liters
1 milliliter	= 0.0353 ounce	1 ounce	= 29.57 milliliters

A.42 Measures of Weight

The basic unit of weight in the Metric system is the gram. One cubic centimeter of water at maximum density weighs one gram, and thus there is a direct, simple relation between volume of water and weight in the Metric system.

1 kilogram (kg) = 1000 grams (gm)
1 gram (gm) = 1000 milligrams (mg)
1 milligram (mg) = 1000 micrograms (μg)

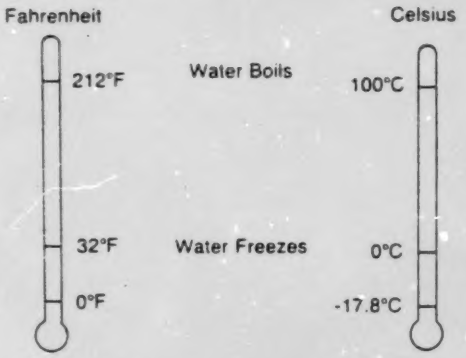
Grams are usually used in place of ounces, and kilograms are used in place of pounds.

WEIGHT EQUIVALENTS

1 kilogram	= 2.205 pounds	1 pound	= 0.4536 kilogram
1 gram	= 0.0022 pound	1 pound	= 453.6 grams
1 gram	= 0.0353 ounce	1 ounce	= 28.35 grams
1 gram	= 15.43 grains	1 grain	= 0.0648 gram

A.43 Temperature

Just as the operator should become familiar with the Metric system, you should also become familiar with the centigrade (Celsius) scale for measuring temperature. There is nothing magical about the centigrade scale — it is simply a different size than the Fahrenheit scale. The two scales compare as follows:



The two scales are related in the following manner:

$$\boxed{\begin{aligned} \text{Fahrenheit} &= (°C \times 9/5) + 32° \\ \text{Celsius} &= (°F - 32°) \times 5/9 \end{aligned}}$$

Example: Convert 20° Celsius to Fahrenheit.

$$F = (°C \times 9/5) + 32°$$
$$F = (20° \times 9/5) + 32°$$
$$F = \frac{180°}{5} + 32°$$
$$= 36° + 32°$$
$$= 68°F$$

Example: Convert −10°C to °F.

$$F = (-10° \times 9/5) + 32°$$
$$F = -90°/5 + 32°$$
$$= -18° + 32°$$
$$= 14°F$$

Example: Convert −13°F to °C.

$$C = (°F - 32°) \times \frac{5}{9}$$

$$C = (-13° - 32°) \times \frac{5}{9}$$

$$= -45° \times \frac{5}{9}$$

$$= -5° \times 5$$

$$= -25°C$$

A.44 Milligrams per Liter

Milligrams per liter (mg/*L*) is a unit of measurement used in laboratory and scientific work to indicate very small concentrations of dilutions. Since water contains small concentrations of dissolved substances and solids, and since small amounts of chemical compounds are sometimes used in water treatment processes, the term milligrams per liter is also common in treatment plants. It is a weight/volume relationship.

As previously discussed:

1000 liters = 1 cubic meter = 1,000,000 cubic centimeters

Therefore

1 liter = 1000 cubic centimeters

Since one cubic centimeter of water weighs one gram.

1 liter of water = 1000 grams or 1,000,000 milligrams

$$\boxed{\frac{1\text{ milligram}}{\text{liter}} = \frac{1\text{ milligram}}{1{,}000{,}000\text{ milligrams}} = \frac{1\text{ part}}{\text{million parts}} = \text{1 part per million (ppm)}}$$

Milligrams per liter and parts per million (parts) may be used interchangeably as long as the liquid density is 1.0 gm/cu cm or 62.43 lb/cu ft. A concentration of 1 milligram/liter (mg/*L*) or 1 ppm means that there is 1 part of substance by weight for every 1 million parts of water. A concentration of 10 mg/*L* would mean 10 parts of substance per million parts of water.

To get an idea of how small 1 mg/*L* is, divide the numerator and denominator of the fraction by 10,000. This, of course, does not change its value since, 10,000 ÷ 10,000 is equal to one.

$$\boxed{1\frac{\text{mg}}{L} = \frac{1\text{ mg}}{1{,}000{,}000\text{ mg}} = \frac{1/10{,}000\text{ mg}}{1{,}000{,}000/10{,}000\text{ mg}} = \frac{0.0001\text{ mg}}{100\text{ mg}} = 0.0001\%}$$

Therefore, 1 mg/*L* is equal to one ten-thousandth of a percent, or

1% is equal to 10,000 mg/*L*

To convert mg/*L* to %, move the decimal point four places or numbers to the left.

Working problems using milligrams per liter or parts per million is a part of everyday operation in most water treatment plants.

A.45 Example Problems

Example: Raw water flowing into a plant at a rate of five million pounds per day is prechlorinated at 5 mg/*L*. How many pounds of chlorine are used per day?

$$5\text{ mg}/L = \frac{5\text{ lbs chlorine}}{\text{million lbs water}}$$

$$\text{Chlorine Feed, lbs/day} = \text{Concentration, lbs/M lbs} \times \text{Flow, lbs/day}$$

$$= \frac{5\text{ lbs}}{\cancel{\text{million lbs}}} \times \frac{5\ \cancel{\text{million lbs}}}{\text{day}}$$

$$= 25\text{ lbs/day}$$

There is one thing that is unusual about the above problem and that is the flow is reported in pounds per day. In most treatment plants, flow is reported in terms of gallons per minute or gallons per day. To convert these flow figures to weight, an additional conversion factor is needed. One gallon of water weighs 8.34 pounds. Using this factor, it is possible to convert flow in gallons per day to flow in pounds per day.

Example: A well pump with a flow of 3.5 million gallons per day (MGD) chlorinates the water with 2.0 mg/*L* chlorine. How many pounds of chlorine are used per day?

$$\text{Flow, lbs/day} = \text{Flow, } \frac{\text{M gal}}{\text{day}} \times 8.34\ \frac{\text{lb}}{\text{gal}}$$

$$= \frac{3.5\text{ million }\cancel{\text{gal}}}{\text{day}} \times \frac{8.34\text{ lbs}}{\cancel{\text{gal}}}$$

$$= 29.19\text{ million lbs/day}$$

$$\text{Chlorine Feed, lbs/day} = \text{Level, mg}/L \times \text{Flow, M lb/day}$$

$$= \frac{2.0\ \cancel{\text{mg}}^{*}}{\cancel{\text{million mg}}} \times \frac{29.10\ \cancel{\text{million}}\text{ lbs}}{\text{day}}$$

$$= 58.38\text{ lbs/day}$$

In solving the above problem, a relation was used that is most important to understand and commit to memory.

$$\boxed{\text{Feed, lbs/day} = \text{Flow, MGD} \times \text{Dose, mg}/L \times 8.34\text{ lbs/gal}}$$

Example: A chlorinator is set to feed 50 pounds of chlorine per day to a flow of 0.8 MGD. What is the chlorine dose in mg/*L*?

$$\text{Conc. or Dose, mg}/L = \frac{\text{lbs/day}}{\text{MGD} \times 8.34\text{ lb/gal}}$$

$$= \frac{50\text{ lb/day}}{0.80\text{ MG/day} \times 8.34\text{ lb/gal}}$$

$$= \frac{50\text{ lb}}{6.672\text{ M lb}}$$

$$= 7.5\text{ mg}/L\text{, or 7.5 ppm}$$

Example: A pump delivers 500 gallons per minute to a water treatment plant. Alum is added at 10 mg/*L*. How much alum is used in pounds per day?

---

[*] Remember that $\frac{1\text{ mg}}{\text{M mg}} = \frac{1\text{ lb}}{\text{M lb}}$. They are identical ratios.

$$\text{Flow, MGD} = \text{Flow, GPM} \times 60\ \text{min/hr} \times 24\ \text{hr/day}$$

$$= \frac{500\ \text{gal}}{\cancel{\text{min}}} \times \frac{60\ \cancel{\text{min}}}{\cancel{\text{hr}}} \times \frac{24\ \cancel{\text{hr}}}{\text{day}}$$

$$= 720{,}000\ \text{gal/day}$$

$$= 0.72\ \text{MGD}$$

$$\text{Alum Feed, lbs/day} = \text{Flow, MGD} \times \text{Dose, mg/}L \times 8.34\ \text{lbs/gal}$$

$$= \frac{0.72\ \cancel{\text{M}}\ \cancel{\text{gal}}}{\text{day}} \times \frac{10\ \cancel{\text{mg}}}{\cancel{\text{M}}\ \cancel{\text{mg}}} \times \frac{8.34\ \text{lb}}{\cancel{\text{gal}}}$$

$$= 60.048\ \text{lbs/day or about 60 lbs/day}$$

A.5 WEIGHT-VOLUME RELATIONS

Another factor for the operator to remember, in addition to the weight of a gallon of water, is the weight of a cubic foot of water. One cubic foot of water weighs 62.4 lbs. If these two weights are divided, it is possible to determine the number of gallons in a cubic foot.

$$\frac{62.4\ \cancel{\text{pounds}}/\text{cu ft}}{8.34\ \cancel{\text{pounds}}/\text{gal}} = 7.48\ \text{gal/cu ft}$$

Thus we have another very important relationship to commit to memory.

$$\boxed{8.34\ \text{lb/gal} \times 7.48\ \text{gal/cu ft} = 62.4\ \text{lb/cu ft}}$$

It is only necessary to remember two of the above items since the third may be found by calculation. For most problems, 8⅓ lbs/gal and 7½ gal/cu ft will provide sufficient accuracy.

Example: Change 1000 cu ft of water to gallons.

1000 cu ft × 7.48 gal/cu ft = 7480 gallons

Example: What is the weight of three cubic feet of water?

62.4 lb/cu ft × 3 cu ft = 187.2 lbs

Example: The net weight of a tank of water is 750 lbs. How many gallons does it contain?

$$\frac{750\ \cancel{\text{lb}}}{8.34\ \cancel{\text{lb}}/\text{gal}} = 90\ \text{gals}$$

A.6 FORCE, PRESSURE, AND HEAD

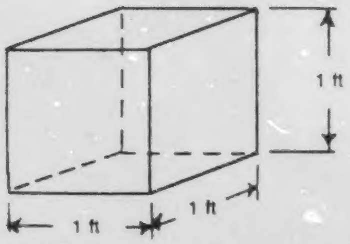
In order to study the forces and pressures involved in fluid flow it is first necessary to define the terms used.

FORCE:	The push exerted by water on any surface being used to confine it. Force is usually expressed in pounds, tons, grams, or kilograms.
PRESSURE:	The force per unit area. Pressure can be expressed in many ways, but the most common term is pounds per square inch (psi).
HEAD:	Vertical distance from the water surface to a reference point below the surface. Usually expressed in feet or meters.

An *EXAMPLE* should serve to illustrate these terms.

If water were poured into a one-foot cubical container, the *FORCE* acting on the bottom of the container would be 62.4 pounds.

The *PRESSURE* acting on the bottom would be 62.4 pounds per square foot. The area of the bottom is also 12 in × 12 in = 144 in^2. Therefore, the pressure may also be expressed as:



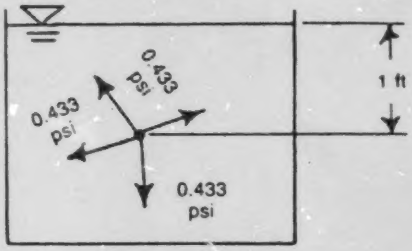
$$\text{Pressure, psi} = \frac{62.4\ \text{lb}}{\text{sq ft}} = \frac{62.4\ \text{lb/sq ft}}{144\ \text{sq in/sq ft}}$$

$$= 0.433\ \text{lb/sq in}$$

$$= 0.433\ \text{psi}$$

Since the height of the container is one foot, the *HEAD* would be one foot.

The pressure in any vessel at one foot of depth or one foot of head is 0.433 psi acting in any direction.



If the depth of water in the previous example were increased to two feet, the pressure would be:

$$p = \frac{2\ (62.4\ \text{lb})}{144\ \text{sq in}} = \frac{124.8\ \text{lb}}{144\ \text{sq in}} = 0.866\ \text{psi}$$

Therefore we can see that for every foot of head, the pressure increases by 0.433 psi. Thus, the general formula for pressure becomes:

$$\boxed{p,\ \text{psi} = 0.433\ (H,\ \text{ft})}$$

H = feet of head

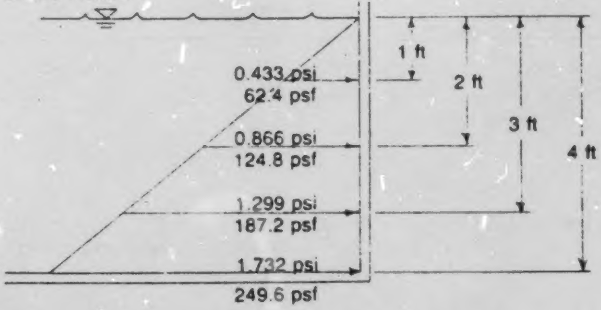
p = pounds per square *INCH* of pressure

$$\boxed{P,\ \text{lb/sq ft} = 62.4\ (H,\ \text{ft})}$$

H = feet of head

P = pounds per square *FOOT* of pressure

We can now draw a diagram of the pressure acting on the side of a tank. Assume a four-foot deep tank. The pressures shown on the tank are gage pressures. These pressures do not include the atmospheric pressure acting on the surface of the water.



$p_0 = 0.433 \times 0 = 0.0$ psi

$p_1 = 0.433 \times 1 = 0.433$ psi

$p_2 = 0.433 \times 2 = 0.866$ psi

$p_3 = 0.433 \times 3 = 1.299$ psi

$p_4 = 0.433 \times 4 = 1.732$ psi

$P_0 = 62.4 \times 0 = 0.0$ lb/sq ft

$P_1 = 62.4 \times 1 = 62.4$ lb/sq ft

$P_2 = 62.4 \times 2 = 124.8$ lb/sq ft

$P_3 = 62.4 \times 3 = 187.2$ lb/sq ft

$P_4 = 62.4 \times 4 = 249.6$ lb/sq ft

The average *PRESSURE* acting on the tank wall is 1.732 psi/2 = 0.866 psi, or 249.2 psf/2 = 124.8 psf. We divided by two to obtain the average pressure because there is zero pressure at the top and 1.732 psi pressure on the bottom of the wall.

If the wall were five feet long, the pressure would be acting over the entire 20 square foot (5 ft × 4 ft) area of the wall. The total force acting to push the wall would be:

Force, lb = (Pressure, lb/sq ft)(Area, sq ft)

= 124.8 lb/sq ft × 20 sq ft

= 2496 lbs

If the pressure in psi were used, the problem would be similar:

Force, lb = (Pressure, lb/sq in)(Area, sq in)

= 0.866 psi × 48 in × 60 in

= 2494 lb*

The general formula, then, for finding the total force acting on a side wall of a tank is:

$$\boxed{F = 31.2 \times H^2 \times L}$$

F = force in pounds

H = head in feet

L = length of wall in feet

31.2 = constant with units of lbs/cu ft and considers the fact that the force results from H/2 or half the depth of the water which is the average depth. The force is exerted at H/3 from the bottom.

Example: Find the force acting on a five-foot long wall in a four-foot deep tank.

Force, lb = 31.2 (Head, ft)^2 (Length, ft)

= 31.2 lb/cu ft × (4 ft)^2 × 5 ft

= 2496 lbs

Occasionally an operator is warned: *NEVER EMPTY A TANK DURING PERIODS OF HIGH GROUNDWATER.* Why? The pressure on the bottom of the tank caused by the water surrounding the tank will tend to float the tank like a cork if the upward force of the water is greater than the weight of the tank.

$$\boxed{F = 62.4 \times H \times A}$$

F = upward force in pounds

H = head of water on tank bottom in feet

A = area of bottom of tank in square feet

62.4 = a constant with units of lbs/cu ft

This formula is approximately true if the tank doesn't crack, leak, or start to float.

Example: Find the upward force on the bottom of an empty tank caused by a groundwater depth of 8 feet above the tank bottom. The tank is 20 ft wide and 40 ft long.

Force, lb = 62.4 (Head, ft)(Area, sq ft)

= 62.4 lb/cu ft × 8 ft × 20 ft × 40 ft

= 399,400 lb

A.7 VELOCITY AND FLOW RATE

A.70 Velocity

The velocity of a particle or substance is the speed at which it is moving. It is expressed by indicating the length of travel and how long it takes to cover the distance. Velocity can be expressed in almost any distance and time units. For instance, a car may be traveling at a rate of 280 miles per five hours. However, it is normal to express the distance traveled per unit time. The above example would then become:

$$\text{Velocity, mi/hr} = \frac{280 \text{ miles}}{5 \text{ hours}}$$

$$= 56 \text{ miles/hour}$$

The velocity of water in a channel, pipe, or other conduit can be expressed in the same way. If the particle of water travels 600 feet in five minutes, the velocity is:

$$\text{Velocity, ft/min} = \frac{\text{distance, ft}}{\text{time, minutes}}$$

$$= \frac{600 \text{ ft}}{5 \text{ min}}$$

$$= 120 \text{ ft/min}$$

If you wish to express the velocity in feet per second, multiply by 1 min/60 seconds.

NOTE: $\frac{1 \text{ minute}}{60 \text{ seconds}}$ is like $\frac{1}{1}$ and does not change the relative value of the answer. It only changes the form of the answer.

Velocity, ft/sec = (Velocity, ft/min)(1 min/60 sec)

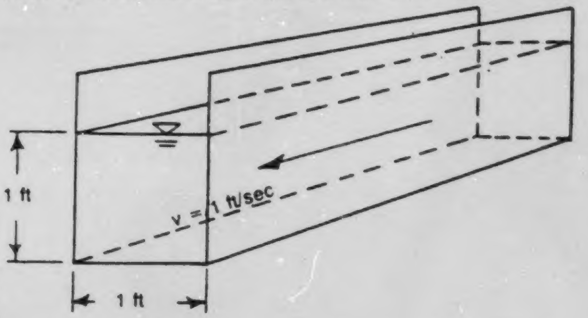
$$= \frac{120 \text{ ft}}{\cancel{\text{min}}} \times \frac{1\ \cancel{\text{min}}}{60 \text{ sec}}$$

$$= \frac{120 \text{ ft}}{60 \text{ sec}}$$

$$= 2 \text{ ft/sec}$$

A.71 Flow Rate

If water in a one-foot wide channel is one foot deep, then the cross sectional area of the channel is 1 ft × 1 ft = 1 sq ft.



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* Difference in answer due to rounding off of decimal points.

If the velocity in this channel is 1 ft per second, then each second a body of water 1 sq ft in area and 1 ft long will pass a given point. The volume of this body of water would be 1 cubic foot. Since one cubic foot of water would pass by every second, the flow rate would be equal to 1 cubic foot per second, or 1 cfs.

To obtain the flow rate in the above example the velocity was multiplied by the cross sectional area. This is another important general formula.

$\boxed{Q = V \times A}$ Q = flow rate, cfs or cu ft/sec
V = velocity, ft/sec
A = area, sq ft

Example: A rectangular channel 3 feet wide contains water 2 feet deep and flowing at a velocity of 1.5 feet per second. What is the flow rate in cfs?

$$Q = V \times A$$

Flow rate, cfs = Velocity, ft/sec × Area, sq ft
= 1.5 ft/sec × 3 ft × 2 ft
= 9 cu ft/sec

Example: Flow in a 2.5 foot wide channel is 1.4 ft deep and measures 11.2 cfs. What is the average velocity?

In this problem we want to find the velocity. Therefore, we must rearrange the general formula to solve for velocity.

$$V = \frac{Q}{A}$$

$$\text{Velocity, ft/sec} = \frac{\text{Flow Rate, cu ft/sec}}{\text{Area, sq ft}}$$

$$= \frac{11.2\text{ cu ft/sec}}{2.5\text{ ft} \times 1.4\text{ ft}}$$

$$= \frac{11.2\text{ ft/sec}}{3.5}$$

$$= 3.2\text{ ft/sec}$$

Example: Flow in an 8-inch pipe is 500 GPM. What is the average velocity?

Area, sq ft = 0.785 (Diameter, ft)^2
= 0.785 (8/12 ft)^2
= 0.785 ($\frac{2}{3}$ ft)^2
= 0.785 ($\frac{2}{3}$ ft)($\frac{2}{3}$ ft)
= 0.785 (4/9 ft^2)
= 0.35 sq ft

$$\text{Flow, cfs} = \text{Flow, gal/min} \times \frac{\text{cu ft}}{7.48\text{ gal}} \times \frac{1\text{ min}}{60\text{ sec}}$$

$$= \frac{500\text{ gal}}{\text{min}} \times \frac{\text{cu ft}}{7.48\text{ gal}} \times \frac{1\text{ min}}{60\text{ sec}}$$

$$= \frac{500\text{ cu ft}}{448.8\text{ sec}}$$

$$= 1.114\text{ cfs}$$

$$\text{Velocity, ft/sec} = \frac{\text{Flow, cu ft/sec}}{\text{Area, sq ft}}$$

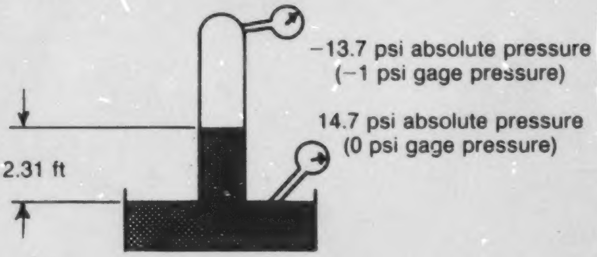
$$= \frac{1.114\text{ ft}^3\text{/sec}}{0.35\text{ ft}^2}$$

$$= 3.18\text{ ft/sec}$$

A.8 PUMPS

A.80 Pressure

Atmospheric pressure at sea level is approximately 14.7 psi. This pressure acts in all directions and on all objects. If a tube is placed upside down in a basin of water and a 1 psi partial vacuum is drawn on the tube, the water in the tube will rise 2.31 feet.



NOTE: 1 ft of water = 0.433 psi; therefore,

$$1\text{ psi} = \frac{1}{0.433}\text{ ft} = 2.31\text{ ft of water}$$

The action of the partial vacuum is what gets water out of a sump or well and up to a pump. It is not sucked up, but it is pushed up by atmospheric pressure on the water surface in the sump. If a complete vacuum could be drawn, the water would rise 2.31 × 14.7 = 33.9 feet; but this is impossible to achieve. The practical limit of the suction lift of a positive displacement pump is about 22 feet, and that of a centrifugal pump is 15 feet.

A.81 Work

Work can be expressed as lifting a weight a certain vertical distance. It is usually defined in terms of foot-pounds.

Example: A 165-pound man runs up a flight of stairs 20 feet high. How much work did he do?

Work, ft-lb = Weight, lb × Height, ft
= 165 lb × 20 ft
= 3300 ft-lb

A.82 Power

Power is a rate of doing work and is usually expressed in foot-pounds per minute.

Example: If the man in the above example runs up the stairs in three seconds, how much power has he exerted?

$$\text{Power, ft-lbs/sec} = \frac{\text{Work, ft-lb}}{\text{Time, sec}}$$

$$= \frac{3300\text{ ft-lbs}}{3\ \cancel{\text{sec}}} \times \frac{60\ \cancel{\text{sec}}}{\text{minute}}$$

$$= 66{,}000\text{ ft-lb/min}$$

A.83 Horsepower

Horsepower is also a unit of power. One horsepower is defined as 33,000 ft-lbs per minute or 746 watts.

Example: How much horsepower has the man in the previous example exerted as he climbs the stairs?

$$\text{Horsepower, HP} = (\text{Power, ft-lb/min})\left(\frac{\text{HP}}{33{,}000 \text{ ft-lb/min}}\right)$$

$$= 66{,}000 \text{ ft-lb/min} \times \frac{\text{Horsepower}}{33{,}000 \text{ ft-lb/min}}$$

$$= 2 \text{ HP}$$

Work is also done by lifting water. If the flow from a pump is converted to a weight of water and multiplied by the vertical distance it is lifted, the amount of work or power can be obtained.

$$\text{Horsepower, HP} = \frac{\text{Flow, gal}}{\text{min}} \times \text{Lift, ft} \times \frac{8.34 \text{ lb}}{\text{gal}} \times \frac{\text{Horsepower}}{33{,}000 \text{ ft-lb/min}}$$

Solving the above relation, the amount of horsepower necessary to lift the water is obtained. This is called water horsepower.

$$\text{Water, HP} = \frac{(\text{Flow, GPM})(\text{H, ft})}{3960^{*}}$$

However, since pumps are not 100% efficient (they cannot transmit all the power put into them), the horsepower supplied to a pump is greater than the water horsepower. Horsepower supplied to the pump is called brake horsepower.

$$\boxed{\text{Brake, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p}}$$

E_p = Efficiency of Pump (Usual range 50-85%, depending on type and size of pump)

Motors are also not 100% efficient; therefore, the power supplied to the motor is greater than the motor transmits.

$$\boxed{\text{Motor, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p \times E_m}}$$

E_m = Efficiency of motor (Usual range 80-95%, depending on type and size of motor)

The above formulas have been developed for the pumping of water and wastewater which have a specific gravity of 1.0. If other liquids are to be pumped, the formulas must be multiplied by the specific gravity of the liquid.

Example: A flow of 500 GPM of water is to be pumped against a total head of 100 feet by a pump with an efficiency of 70%. What is the pump horsepower?

$$\text{Brake, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p}$$

$$= \frac{500 \times 100}{3960 \times 0.70}$$

$$= 18 \text{ HP}$$

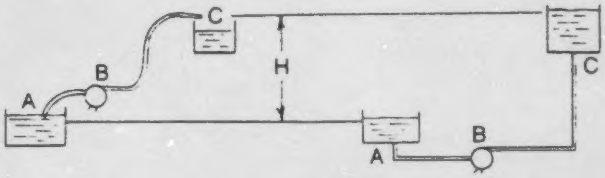
Example: Find the horsepower required to pump gasoline (specific gravity = 0.75) in the above problem.

$$\text{Brake, HP} = \frac{500 \times 100 \times 0.75}{3960 \times 0.70}$$

$$= 13.5 \text{ HP}$$ (gasoline is lighter and requires less horsepower)

A.84 Head

Basically, the head that a pump must work against is determined by measuring the vertical distance between the two water surfaces, or the distance the water must be lifted. This is called the static head. Two typical conditions for lifting water are shown below.



If a pump were designed in the above examples to pump only against head H, the water would never reach the intended point. The reason for this is that the water encounters friction in the pipelines. Friction depends on the roughness and length of pipe, the pipe diameter, and the flow velocity. The turbulence caused at the pipe entrance (point A); the pump (point B); the pipe exit (point C); and at each elbow, bend, or transition also adds to these friction losses. Tables and charts are available in Section A.88 for calculation of these friction losses so they may be added to the measured or static head to obtain the total head. For short runs of pipe which do not have high velocities, the friction losses are generally less than 10 percent of the static head.

Example: A pump is to be located eight feet above a wet well and must lift 1.8 MGD another 50 feet to a storage reservoir. If the pump has an efficiency of 75% and the motor an efficiency of 90%, what is the cost of the power consumed if one kilowatt hour costs 4 cents?

Since we are not given the length or size of pipe and the number of elbows or bends, we will assume friction to be 10% of static head.

$$\text{Static Head, ft} = \text{Suction Lift, ft} + \text{Discharge Head, ft}$$

$$= 8 \text{ ft} + 50 \text{ ft}$$

$$= 58 \text{ ft}$$

$$\text{Friction Losses, ft} = 0.1 (\text{Static Head, ft})$$

$$= 0.1 (58 \text{ ft})$$

$$= 5.8 \text{ ft}$$

$$\text{Total Dynamic Head, ft} = \text{Static Head, ft} + \text{Friction Losses, ft}$$

$$= 58 \text{ ft} + 5.8 \text{ ft}$$

$$= 63.8 \text{ ft}$$

$$\text{Flow, GPM} = \frac{1{,}800{,}000 \text{ gal}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{24 \cancel{\text{hr}}} \times \frac{1 \cancel{\text{hr}}}{60 \text{ min}}$$

$$= 1250 \text{ GPM}$$ (assuming pump runs 24 hours per day)

$$^{*}\ \frac{8.34 \text{ lb}}{\text{gal}} \times \frac{\text{HP}}{33{,}000 \text{ ft-lb/min}} = \frac{1}{3960}$$

1 gallon weighs 8.34 pounds and 1 horsepower is the same as 33,000 ft-lb/min.

H or Head in feet is the same as Lift in feet.

$$\text{Motor, HP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times E_p \times E_m}$$

$$= \frac{1250 \times 63.8}{3960 \times 0.75 \times 0.9}$$

$$= 30\ \text{HP}$$

$$\text{Kilowatt-hrs} = 30\ \cancel{\text{HP}} \times 24\ \text{hrs/day} \times 0.746\ \text{kw}/\cancel{\text{HP}}^{*}$$

$$= 537\ \text{kilowatt-hrs/day}$$

$$\text{Cost} = \text{KWH} \times \$0.04/\text{KWH}$$

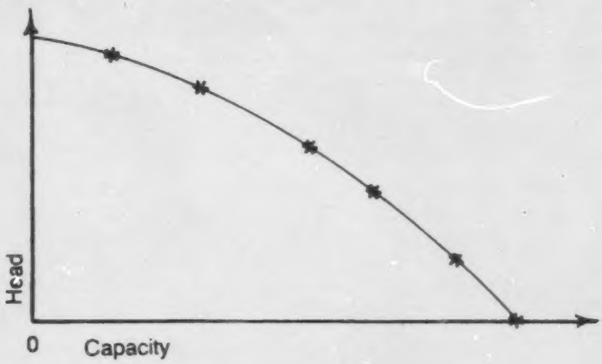
$$= 537 \times 0.04$$

$$= \$21.48/\text{day}$$

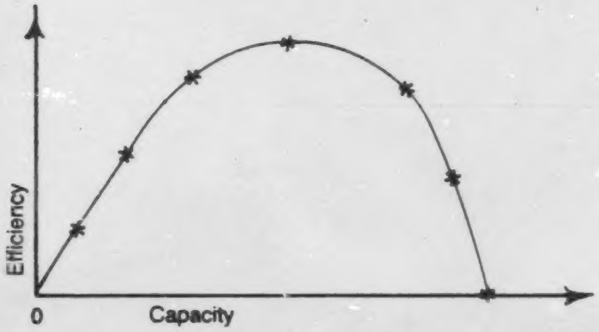
A.85 Pump Characteristics

The discharge of a centrifugal pump, unlike a positive displacement pump, can be made to vary from zero to a maximum capacity which depends on the speed, head, power, and specific impeller design. The interrelation of capacity, efficiency, head, and power is known as the characteristics of the pump.

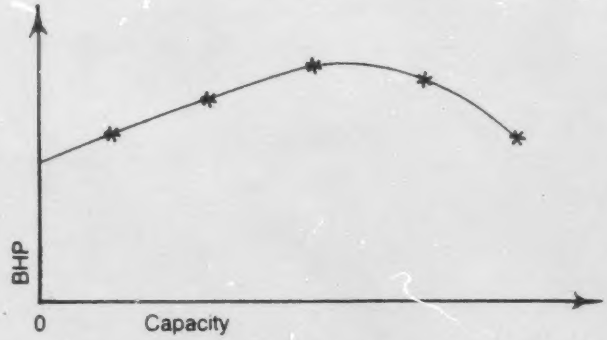
The first relation normally looked at when searching for a pump is the head vs. capacity. The head of a centrifugal pump normally rises as the capacity is reduced. If the values are plotted on a graph they appear as follows:



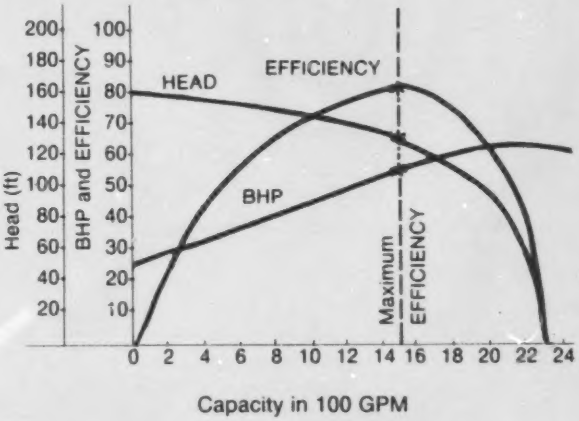
Another important characteristic is the pump efficiency. It begins from zero at no discharge, increases to a maximum, and then drops as the capacity is increased. Following is a graph of efficiency vs. capacity:



The last important characteristic is the brake horsepower or the power input to the pump. The brake horsepower usually increases with increasing capacity until it reaches a maximum, then it normally reduces slightly.



These pump characteristic curves are quite important. Pump sizes are normally picked from these curves rather than calculations. For ease of reading, the three characteristic curves are normally plotted together. A typical graph of pump characteristics is shown as follows:



The curves show that the maximum efficiency for the particular pump in question occurs at approximately 1475 GPM, a head of 132 feet, and a brake horsepower of 58. Operating at this point the pump has an efficiency of approximately 85%. This can be verified by calculation:

$$\text{BHP} = \frac{\text{Flow, GPM} \times \text{H, ft}}{3960 \times \text{E}}$$

As previously explained, a number can be written over one without changing its value:

$$\frac{\text{BHP}}{1} = \frac{\text{GPM} \times \text{H}}{3960 \times \text{E}}$$

Since the formula is now in ratio form, it can be cross multiplied.

$$\text{BHP} \times 3960 \times \text{E} = \text{GPM} \times \text{H} \times 1$$

Solving for E,

$$\text{E} = \frac{\text{GPM} \times \text{H}}{3960 \times \text{BHP}}$$

$$\text{E} = \frac{1475\ \text{GPM} \times 132\ \text{ft}}{3960 \times 58\ \text{HP}}$$

$$= 0.85 \text{ or } 85\% \text{ (Check)}$$

---

[*] See Conversion Tables — Section A.10, "Power."

The preceding is only a brief description of pumps to familiarize the operator with their characteristics. The operator does not normally specify the type and size of pump needed at a plant. If a pump is needed, the operator should be able to supply the information necessary for a pump supplier to provide the best possible pump for the lowest cost. Some of the information needed includes:

1. Flow range desired
2. Head conditions
   a. Suction head or lift
   b. Pipe and fitting friction head
   c. Discharge head
3. Type of fluid pumped and temperature
4. Pump location

A.86 Evaluation of Pump Performance

1. Capacity

Sometimes it is necessary to determine the capacity of a pump. This can be accomplished by determining the time it takes a pump to fill or empty a portion of a wet well or diversion box when all inflow is blocked off.

EXAMPLE:

a. Measure the size of the wet well.

Length = 10 ft

Width = 10 ft

Depth = 5 ft (We will measure the time it takes to lower the well a distance of five feet)

$$\text{Volume, cu ft} = \text{L, ft} \times \text{W, ft} \times \text{D, ft}$$

$$= 10 \text{ ft} \times 10 \text{ ft} \times 5 \text{ ft}$$

$$= 500 \text{ cu ft}$$

b. Record time for water to drop five feet in wet well.

Time = 10 minutes 30 seconds
= 10.5 minutes

c. Calculate pumping rate or capacity.

$$\text{Pumping Rate, GPM} = \frac{\text{Volume, gallons}}{\text{Time, minutes}}$$

$$= \frac{(500 \text{ cu ft})(7.5 \text{ gal/cu ft})}{10.5 \text{ min}}$$

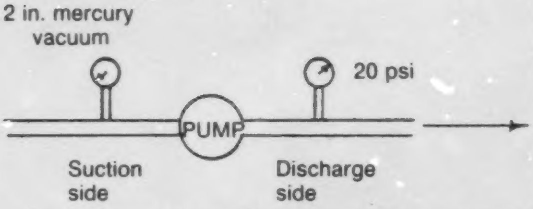
$$= \frac{3750}{10.5}$$

$$= 357 \text{ GPM}$$

If you know the total dynamic head and have the pump's performance curves, you can determine if the pump is delivering at design capacity. If not, try to determine the cause (see Chapter 18, "Maintenance"). After a pump overhaul, the pump's actual performance (flow, head, power and efficiency) should be compared with the pump manufacturer's performance curves. This procedure for calculating the rate of filling or emptying of a wet well or diversion box can be used to calibrate flow meters.

2. Efficiency

To estimate the efficiency of the pump in the previous example, the total head must be known. This head may be estimated by measuring the suction and discharge pres
Assume these were measured as follows:



No additional information is necessary if we assum
pressure gages are at the same height and the pipe di
ters are the same. Both pressure readings must be con
ed to feet.

$$\text{Suction Lift, ft} = 2 \text{ in Mercury} \times \frac{1.133 \text{ ft water}^{*}}{1 \text{ in Mercury}}$$

$$= 2.27 \text{ ft}$$

$$\text{Discharge Head, ft} = 20 \text{ psi} \times 2.31 \text{ ft/psi}^{*}$$

$$= 46.20 \text{ ft}$$

$$\text{Total Head, ft} = \text{Suction Lift, ft} + \text{Discharge Hea}$$

$$= 2.27 \text{ ft} + 46.20 \text{ ft}$$

$$= 48.47 \text{ ft}$$

---

*See Conversion Tables — Section A.10, "Pressure."

Calculate the power output of the pump or water ho
power:

$$\text{Water Horsepower, HP} = \frac{(\text{Flow GPM})(\text{Head, ft})}{3960}$$

$$= \frac{(357 \text{ GPM})(48.47 \text{ ft})}{3960}$$

$$= 4.4 \text{ HP}$$

To estimate the efficiency of the pump, measure
kilowatts drawn by the pump motor. Assume the m
indicates 8000 watts or 8 kilowatts. The manufacturer cl
the electric motor is 80% efficient.

$$\text{Brake Horsepower, HP} = (\text{Power to elec. motor})(\text{motor e}$$

$$= \frac{(8 \text{ kw})(0.80)}{0.746 \text{ kw/HP}}$$

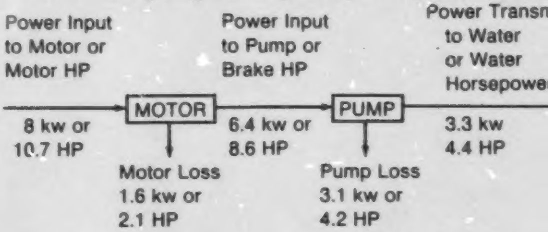
$$= 8.6 \text{ HP}$$

$$\text{Pump Efficiency, \%} = \frac{\text{Water Horsepower, HP} \times 100\%}{\text{Brake Horsepower, HP}}$$

$$= \frac{4.4 \text{ HP} \times 100\%}{8.6 \text{ HP}}$$

$$= 51\%$$

The following diagram may clarify the above problem


Power Input to Motor or Motor HP
Power Input to Pump or Brake HP
Power Transm to Water or Water Horsepowe
MOTOR
PUMP
8 kw or 10.7 HP
6.4 kw or 8.6 HP
3.3 kw 4.4 HP
Motor Loss 1.6 kw or 2.1 HP
Pump Loss 3.1 kw or 4.2 HP

The wire-to-water efficiency is the efficiency of the power input to produce water horsepower.

$$\text{Wire-to-Water Efficiency, \%} = \frac{\text{Water Horsepower, HP}}{\text{Power Input, HP}} \times 100\%$$

$$= \frac{4.4 \text{ HP}}{10.7 \text{ HP}} \times 100\%$$

$$= 41\%$$

A.87 Pump Speed — Performance Relationships

Changing the velocity of a centrifugal pump will change its operating characteristics. If the speed of a pump is changed, the flow, head developed, and power requirements will change. The operating characteristics of the pump will change with speed approximately as follows:

$$\text{Flow, } Q_n = \left[\frac{N_n}{N_r}\right] Q_r$$

$$\text{Head, } H_n = \left[\frac{N_n}{N_r}\right]^2 H_r$$

$$\text{Power, } P_n = \left[\frac{N_n}{N_p}\right]^3 P_r$$

r = rated

n = now

N = pump speed

Actually, pump efficiency does vary with speed; therefore, these formulas are not quite correct. If speeds do not vary by more than a factor of two (if the speeds are not doubled or cut in half), the results are close enough. Other factors contributing to changes in pump characteristic curves include impeller wear and roughness in pipes.

Example: To illustrate these relationships, assume a pump has a rated capacity of 600 GPM, develops 100 ft of head, and has a power requirement of 15 HP when operating at 1500 rpm. If the efficiency remains constant, what will be the operating characteristics if the speed drops to 1200 rpm?

Calculate new flow rate or capacity:

$$\text{Flow, } Q_n = \left[\frac{N_n}{N_r}\right] Q_r$$

$$= \left[\frac{1200 \text{ rpm}}{1500 \text{ rpm}}\right] 600 \text{ GPM}$$

$$= \left[\frac{4}{5}\right] 600 \text{ GPM}$$

$$= (4)\,(120 \text{ GPM})$$

$$= 480 \text{ GPM}$$

Calculate new head:

$$\text{Head, } H_n = \left[\frac{N_n}{N_r}\right]^2 H_r$$

$$= \left[\frac{1200 \text{ rpm}}{1500 \text{ rpm}}\right]^2 100 \text{ ft}$$

$$= \left(\frac{4}{5}\right)^2 100 \text{ ft}$$

$$= \left(\frac{16}{25}\right)(100 \text{ ft})$$

$$= 16\,(4 \text{ ft})$$

$$= 64 \text{ ft}$$

Calculate new power requirement:

$$\text{Power, } P_n = \left[\frac{N_n}{N_r}\right]^3 P_r$$

$$= \left(\frac{1200 \text{ rpm}}{1500 \text{ rpm}}\right)^3 15 \text{ HP}$$

$$= \left(\frac{4}{5}\right)^3 15 \text{ HP}$$

$$= \left(\frac{64}{125}\right) 15 \text{ HP}$$

$$= \left(\frac{64}{25}\right)(3 \text{ HP})$$

$$= 7.7 \text{ HP}$$

A.88 Friction or Energy Losses

Whenever water flows through pipes, valves and fittings, energy is lost due to pipe friction (resistance), friction in valves and fittings, and the turbulence resulting from the flowing water changing its direction. Figure A.1 can be used to convert the friction losses through valves and fittings to lengths of straight pipe that would produce the same amount of friction losses. To estimate the friction or energy losses resulting from water flowing in a pipe system, we need to know:

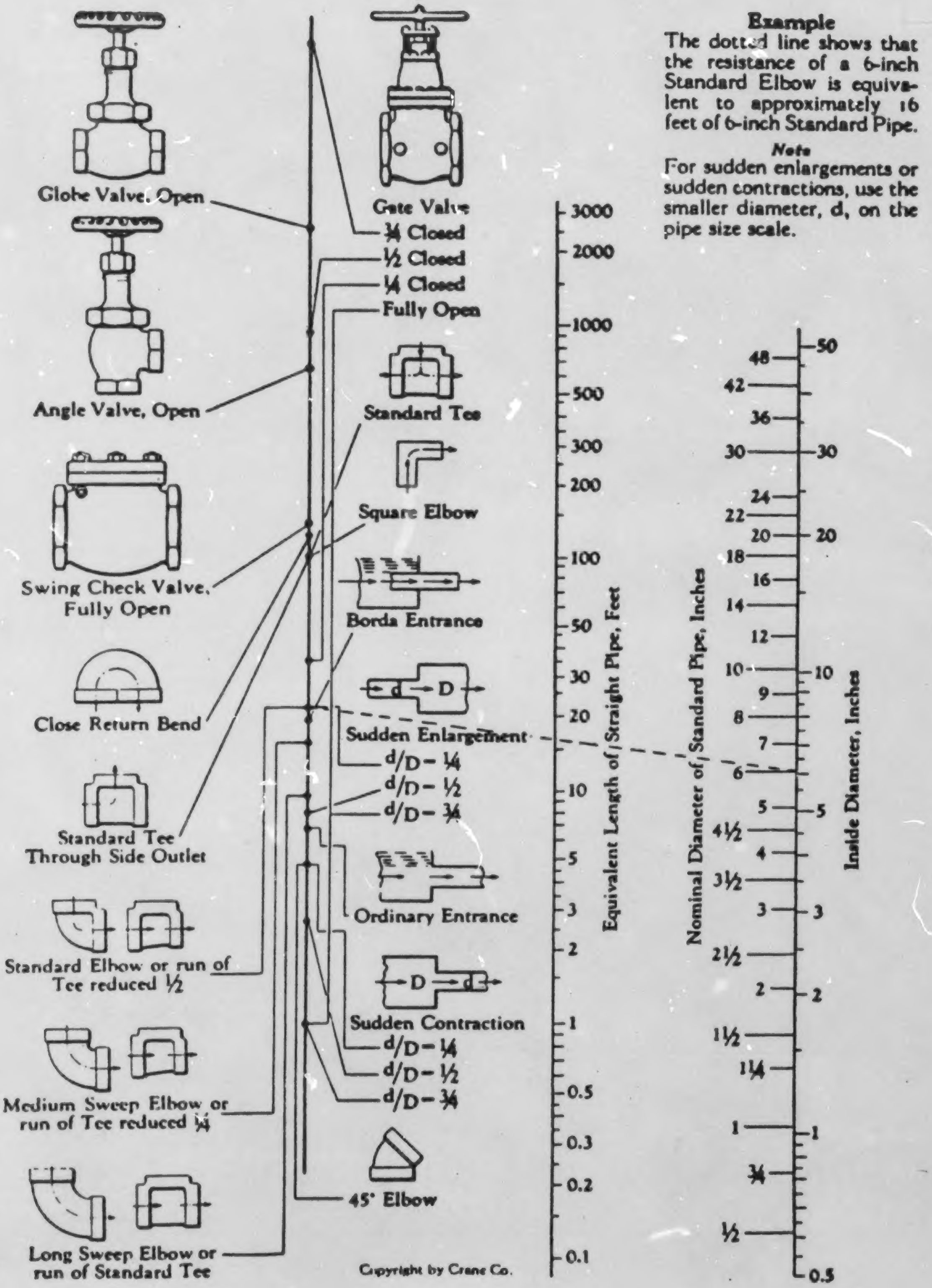
1. Water flow rate,
2. Pipe size or diameter and length, and
3. Number, size and type of valve fittings.

An easy way to estimate friction or energy losses is to follow the following steps:

1. Determine the flow rate;
2. Determine the diameter and length of pipe;
3. Convert all valves and fittings to equivalent lengths of straight pipe (see Figure A.1);
4. Add up total length of equivalent straight pipe; and
5. Estimate friction or energy losses by using Figure A.2. With the flow in GPM and diameter of pipe, find the friction loss per 100 feet of pipe. Multiply this value by equivalent length of straight pipe.

The procedure for using Figure A.1 is very easy. Locate the type of valve or fitting you wish to convert to an equivalent pipe length; find its diameter on the right-hand scale; and draw a straight line between these two points to locate the equivalent length of straight pipe.

Example: Estimate the friction losses in the piping system of a pump station when the flow is 1,000 GPM. The 8-inch suction line is 10 feet long and contains a 90-degree bend (long sweep elbow), a gate valve and an 8-inch by 6-inch reducer at the inlet to the pump. The 6-inch discharge line is 30 feet long and contains a check valve, a gate valve, and three 90-degree bends (medium sweep elbows):



Example

The dotted line shows that the resistance of a 6-inch Standard Elbow is equivalent to approximately 16 feet of 6-inch Standard Pipe.

Note

For sudden enlargements or sudden contractions, use the smaller diameter, d, on the pipe size scale.

Fig. A.1 Resistance of valves and fittings to flow of water

(Reprinted by permission of Crane Co.)

U. S. GPM	0.5 in.		0.75 in.		1 in.		1.25 in.		1.5 in.		2 in.		2.5 in.	
	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.
10	10.56	95.9	6.02	23.0	3.71	6.86	2.15	1.77	1.58	.83	.96	.25	.67	.11
20	.....	.....	12.0	86.1	7.42	25.1	4.29	6.34	3.15	2.94	1.91	.87	1.34	.36
30	.....	.....	.....	.....	11.1	54.6	6.44	13.6	4.73	6.26	2.87	1.82	2.01	.75
40	.....	.....	.....	.....	14.8	95.	8.58	23.5	6.30	10.79	3.82	3.10	2.68	1.28
50	.....	.....	.....	.....	.....	.....	10.7	36.0	7.88	16.4	4.78	4.67	3.35	1.94
60	.....	.....	.....	.....	.....	.....	12.9	51.0	9.46	23.2	5.74	6.59	4.02	2.72
70	.....	.....	.....	.....	.....	.....	15.0	68.8	11.03	31.3	6.69	8.86	4.69	3.63
80	.....	.....	.....	.....	.....	.....	17.2	89.2	12.6	40.5	7.65	11.4	5.36	4.66
90	.....	.....	.....	.....	.....	.....	.....	.....	14.2	51.0	8.60	14.2	6.03	5.82
100	.....	.....	.....	.....	.....	.....	.....	.....	15.8	62.2	9.56	17.4	6.70	7.11
120	.....	.....	.....	.....	.....	.....	.....	.....	18.9	88.3	11.5	24.7	8.04	10.0
140	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13.4	33.2	9.38	13.5
160	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	15.3	43.0	10.7	17.4
180	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.2	54.1	12.1	21.9
200	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	19.1	66.3	13.4	26.7
220	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	21.0	80.0	14.7	32.2
240	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	22.9	95.0	16.1	38.1
260	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	17.4	44.5
280	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	18.8	51.3
300	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	20.1	58.5
350	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	23.5	79.2

U. S. GPM	3 in.		4 in.		5 in.		6 in.		8 in.		10 in.		12 in.		14 in.		16 in.		18 in.		20 in.	
	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.	Vel.	Frict.
20	.91	.15																				
40	1.82	.55	1.02	.13																		
60	2.72	1.17	1.53	.28	.96	.08																
80	3.63	2.02	2.04	.48	1.28	.14	.91	.06														
100	4.54	3.10	2.55	.73	1.60	.20	1.13	.10														
120	5.45	4.40	3.06	1.03	1.92	.29	1.36	.13														
140	6.35	5.93	3.57	1.38	2.25	.38	1.59	.18														
160	7.26	7.71	4.08	1.78	2.57	.49	1.82	.23														
180	8.17	9.73	4.60	2.24	2.89	.61	2.04	.28														
200	9.08	11.9	5.11	2.74	3.21	.74	2.27	.35														
220	9.98	14.3	5.62	3.28	3.53	.88	2.50	.42	1.40	.10												
240	10.9	17.0	6.13	3.88	3.85	1.04	2.72	.49	1.53	.12												
260	11.8	19.8	6.64	4.54	4.17	1.20	2.95	.57	1.66	.14												
280	12.7	22.8	7.15	5.25	4.49	1.38	3.18	.66	1.79	.16												
300	13.6	26.1	7.66	6.03	4.81	1.58	3.40	.75	1.91	.18												
350	.....	.....	8.94	8.22	5.61	2.11	3.97	1.01	2.24	.24												
400	.....	.....	10.20	10.7	6.41	2.72	4.54	1.30	2.55	.30												
450	.....	.....	11.45	13.4	7.22	3.41	5.11	1.54	2.87	.38	1.84	.12										
500	.....	.....	12.8	16.6	8.02	4.16	5.67	2.02	3.19	.46	2.04	.15	1.42	.06								
550	.....	.....	14.0	19.9	8.82	4.98	6.24	2.42	3.51	.56	2.25	.18	1.56	.07								
600	.....	.....	.....	.....	9.62	5.88	6.81	2.84	3.83	.66	2.45	.21	1.70	.08	1.25	.04						
700	.....	.....	.....	.....	11.2	7.93	7.94	3.87	4.47	.88	2.86	.29	1.99	.12	1.46	.05						
800	.....	.....	.....	.....	12.8	10.22	9.08	5.06	5.11	1.14	3.27	.37	2.27	.15	1.67	.07						
900	.....	.....	.....	.....	14.4	12.9	10.2	6.34	5.74	1.44	3.68	.46	2.55	.18	1.88	.09						
1000	.....	.....	.....	.....	.....	.....	11.3	7.73	6.38	1.76	4.09	.57	2.84	.22	2.08	.11						
1100	.....	.....	.....	.....	.....	.....	12.5	9.80	7.02	2.14	4.49	.68	3.12	.27	2.29	.13						
1200	.....	.....	.....	.....	.....	.....	13.6	11.2	7.66	2.53	4.90	.81	3.40	.32	2.50	.15	1.91	.08				
1300	.....	.....	.....	.....	.....	.....	14.7	13.0	8.30	2.94	5.31	.95	3.69	.37	2.71	.17	2.07	.09				
1400	.....	.....	.....	.....	.....	.....	.....	.....	8.93	3.40	5.72	1.09	3.97	.43	2.92	.20	2.23	.10				
1500	.....	.....	.....	.....	.....	.....	.....	.....	9.57	3.91	6.13	1.25	4.26	.49	3.13	.23	2.34	.12				
1600	.....	.....	.....	.....	.....	.....	.....	.....	10.2	4.45	6.54	1.42	4.54	.55	3.33	.25	2.55	.13	2.02	.07		
1700	.....	.....	.....	.....	.....	.....	.....	.....	10.8	5.00	6.94	1.60	4.82	.62	3.54	.29	2.71	.15	2.15	.08		
1800	.....	.....	.....	.....	.....	.....	.....	.....	11.5	5.58	7.35	1.78	5.11	.70	3.75	.32	2.87	.16	2.27	.09		
1900	.....	.....	.....	.....	.....	.....	.....	.....	12.1	6.19	7.76	1.97	5.39	.77	3.96	.35	3.03	.18	2.40	.10		
2000	.....	.....	.....	.....	.....	.....	.....	.....	12.8	6.84	8.17	2.17	5.67	.86	4.17	.39	3.19	.20	2.52	.11		
2500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.2	3.38	7.10	1.33	5.21	.60	3.99	.31	3.15	.17		
3000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.3	4.79	8.51	1.88	6.25	.86	4.79	.44	3.78	.24	3.06	.14
3500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.3	6.55	9.93	2.56	7.29	1.16	5.58	.58	4.41	.32	3.57	.19
4000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	11.3	3.31	8.34	1.50	6.38	.75	5.04	.42	4.08	.24
4500	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.8	4.18	9.38	1.88	7.18	.95	5.67	.53	4.59	.31
5000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.2	5.13	10.4	2.30	7.98	1.17	6.30	.65	5.11	.38
6000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.5	3.31	9.57	1.66	7.56	.92	6.13	.53
7000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.6	4.50	11.2	2.26	8.83	1.24	7.15	.72
8000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.8	2.96	10.09	1.61	8.17	.94
9000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.4	3.73	11.3	2.02	9.19	1.18
10000	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....			12.6	2.48	10.2	1.45

No allowance has been made for age, difference in diameter, or any other abnormal condition of interior surface. Any Factor of Safety must be estimated from the local conditions and the requirements of each particular installation. For general purposes, 15% is a reasonable Factor of Safety.

Fig. A.2 Friction Loss for Water in Feet Per 100 Feet of Pipe

(Reprinted from the 10th Edition of the Standards of the Hydraulic Institute, 122 East 42nd Street, New York)

SUCTION LINE (8-inch diameter)

Item	Equivalent Length, ft
1. Length of pipe	10
2. 90-degree bend	14
3. Gate valve	4
4. 8-inch by 6-inch reducer	17
5. Ordinary entrance	12
Total equivalent length	57 feet

Friction loss (Fig. A.2) = 1.76 ft/100 ft of pipe

DISCHARGE LINE (6-inch diameter)

Item	Equivalent Length, ft
1. Length of pipe	30
2. Check valve	38
3. Gate valve	4
4. Three 90-degree bends (3) (14)	42
Total equivalent length	114 feet

Friction loss (Fig. A.2) = 7.73 ft/100 ft of pipe

Estimate the total friction losses in pumping system for a flow of 1,000 GPM.

SUCTION

Loss = (1.76 ft/100 ft) (57 ft) = 1.0 Ft

DISCHARGE

Loss = (7.73 ft/100 ft) (115 ft) = 8.9 ft

Total friction losses, ft = 9.9 ft

A.9 STEPS IN SOLVING PROBLEMS

A.90 Identification of Problem

To solve any problem, you have to identify the problem, determine what kind of answer is needed, and collect the information needed to solve the problem. A good approach to this type of problem is to examine the problem and make a list of *KNOWN* and *UNKNOWN* information.

Example: Find the theoretical detention time in a rectangular sedimentation tank 8 feet deep, 30 feet wide, and 60 feet long when the flow is 1.4 MGD.

	Known	Unknown
Depth	= 8 ft	Detention Time, hours
Width	= 30 ft	
Length	= 60 ft	
Flow	= 1.4 MGD	

Sometimes a drawing or sketch will help to illustrate a problem and indicate the knowns, unknowns, and possibly additional information needed.

A.91 Selection of Formula

Most problems involving mathematics in water treatment plant operation can be solved by selecting the proper formula, inserting the known information, and calculating the unknown. In our example, we could look in Chapter 4, "Sedimentation," or in Section A.11 of this chapter, "Basic Formulas," to find a formula for calculating detention time. From Section A.11:

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

To convert the known information to fit the terms in a formula sometimes requires extra calculations. The next step is to *find the values of any terms in the formula that are not in the list of known values.*

Flow, gal/day = 1.4 MGD

= 1,400,000 gal/day

From Section A.30:

Tank Volume, cu ft = (Length, ft)(Width, ft)(Height, ft)

= 60 ft × 30 ft × 8 ft

= 14,400 cu ft

Solution of Problem:

$$\begin{aligned}\text{Detention Time, hrs} &= \frac{(\text{Tank Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}\\ &= \frac{(14{,}400\text{ cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{1{,}400{,}000\text{ gal/day}}\\ &= 1.85\text{ hr}\end{aligned}$$

The remainder of this section discusses the details that must be considered in solving this problem.

A.92 Arrangement of Formula

Once the proper formula is selected, you may have to rearrange the terms to solve for the unknown term. From Section A.71, "Flow Rate," we can develop the formula:

$$\text{Velocity, ft/sec} = \frac{\text{Flow Rate, cu ft/sec}}{\text{Cross-Sectional Area, sq ft}}$$

or

$$V = \frac{Q}{A}$$

In this equation if Q and A were given, the equation could be solved for V. If V and A were known, the equation would have to be rearranged to solve for Q. To move terms from one side of an equation to another, use the following rule:

When moving a term or number from one side of an equation to the other, move the numerator (top) of one side to denominator (bottom) of the other; or from the denominator (bottom) of one side to the numerator (top) of the other.

$$V = \frac{Q}{A} \text{ or } Q = AV \text{ or } A = \frac{Q}{V}$$

If the volume of a sedimentation tank and the desired detention time were given, the detention time formula could be rearranged to calculate the design flow.

$$\text{Detention Time, hrs} = \frac{(\text{Tank Vol., cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

By rearranging the terms

$$\text{Flow, gal/day} = \frac{(\text{Tank Vol., cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Detention Time, hrs}}$$

A.93 Unit Conversions

Each term in a formula or mathematical calculation must be of the correct units. The area of a rectangular clarifier (Area, sq ft = Length, ft × Width, ft) can't be calculated in square feet if the width is given as 246 inches or 20 feet 6 inches. The width must be converted to 20.5 feet. In the example problem, if the tank volume were given in gallons, then the 7.48 gal/cu ft would not be needed. THE UNITS IN A FORMULA MUST ALWAYS BE CHECKED BEFORE ANY CALCULATIONS ARE PERFORMED TO AVOID TIME-CONSUMING MISTAKES.

$$\text{Detention Time, hrs} = \frac{(\text{Tank Volume, cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{\cancel{\text{cu ft}}}{} \times \frac{\cancel{\text{gal}}}{\cancel{\text{cu ft}}} \times \frac{\text{hr}}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{\cancel{\text{gal}}}$$

$$= \text{hr (all other units cancel)}$$

NOTE: We have hours = hr. One should note that the hour unit on both sides of the equation can be cancelled out and nothing would remain. This is one more check that we have the correct units. By rearranging the detention time formula, other unknowns could be determined.

If the design detention time and design flow were known, the required capacity of the tank could be calculated.

$$\text{Tank Volume, cu ft} = \frac{(\text{Detention Time, hr})(\text{Flow, gal/day})}{(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}$$

If the tank volume and design detention time were known, the design flow could be calculated.

$$\text{Flow, gal/day} = \frac{(\text{Tank Volume, cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}{\text{Detention Time, hrs}}$$

Rearrangement of the detention time formula to find other unknowns illustrates the need to always use the correct units.

A.94 Calculations

Sections A.12, "Multiplication," and A.13, "Division," outline the steps to follow in mathematical calculations. In general, do the calculations inside parentheses ( ) first and brackets [ ] next. Calculations should be done above and below the divison line before dividing.

$$\text{Detention Time, hrs} = \frac{[(\text{Tank, Volume, cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})]}{\text{Flow, gal/day}}$$

$$= \frac{[(14{,}400\ \text{cu ft})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})]}{1{,}400{,}000\ \text{gal/day}}$$

$$= \frac{2{,}585{,}088\ \text{gal-hr/day}}{1{,}400{,}000\ \text{gal/day}}$$

$$= 1.85\text{, or}$$

$$= 1.9\ \text{hr}$$

A.95 Significant Figures

In calculating the detention time in the previous section, the answer is given as 1.9 hr. The answer could have been calculated:

$$\text{Detention Time,hrs} = \frac{2{,}585{,}088\ \text{gal-hr/day}}{1{,}400{,}000\ \text{gal/day}}$$

$$= 1.846491429\ \ldots\ \text{hours}$$

How does one know when to stop dividing? Common sense and significant figures both help.

First, consider the meaning of detention time and the measurements that were taken to determine the knowns in the formula. Detention time in a tank is a theoretical value and assumes that all particles of water throughout the tank move through the tank at the same velocity. This assumption is not correct; therefore, detention time can only be a representative time for some of the water particles.

Will the flow of 1.4 MGD be constant throughout the 1.9 hours, and is the flow exactly 1.4 MGD, or could it be 1.35 MGD or 1.428 MGD? A carefully calibrated flow meter may give a reading within 2% of the actual flow rate. Flows into a tank fluctuate and flow meters do not measure flows extremely accurately; so the detention time again appears to be a representative or typical detention time.

Tank dimensions are probably satisfactory within 0.1 ft. A flow meter reading of 1.4 MGD is less precise and it could be 1.3 or 1.5 MGD. A 0.1 MGD flow meter error when the flow is 1.4 MGD is (0.1/1.4) × 100% = 7% error. A detention time of 1.9 hours, based on a flow meter reading error of plus or minus 7%, also could have the same error or more, even if the flow was constant. Therefore, the detention time error could be 1.9 hours × 0.07 = ±0.13 hours.

In most of the calculations in the operation of water treatment plants, the operator uses measurements determined in the lab or read from charts, scales, or meters. The accuracy of every measurement depends on the sample being measured, the equipment doing the measuring, and the operator reading or measuring the results. Your estimate is no better than the least precise measurement. Do not retain more than one doubtful number.

To determine how many figures or numbers mean anything in an answer, the approach called "significant figures" is used. In the example the flow was given in two significant figures (1.4 MGD), and the tank dimensions could be considered accurate to the nearest tenth of a foot (depth = 9.0 ft) or two significant figures. Since all measurements and the constants contained two significant figures, the results should be reported as two significant figures or 1.9 hours. The calculations are normally carried out to three significant figures (1.85 hours) and rounded off to two significant figures (1.9 hours).

Decimal points require special attention when determining the number of significant figures in a measurement.

Measurement	**Significant Figures**
0.00325	3
11.078	5
21,000.	2

Example: The distance between two points was divided into three sections, and each section was measured by a different group. What is the distance between the two points if each group reported the distance if measured as follows:

Group	**Distance, ft**	**Significant Figures**
A	11,300.	3
B	2,438.9	5
C	87.62	4
Total Distance	13,826.52	

Group A reported the length of the section it measured to three significant figures; therefore, the distance between the two points should be reported as 13,800 feet (3 significant figures).

When adding, substracting, multiplying, or dividing, the number of significant figures in the answer should not be more than the term in the calculations with the least number of significant figures.

A.96 Check Your Results

After having completed your calculations, you should carefully examine your calculations and answer. Does the answer seem reasonable? If possible, have another operator check your calculations before making any operational changes.

A.10 BASIC CONVERSION FACTORS (ENGLISH SYSTEM)

UNITS		
1,000,000	= 1 Million	1,000,000/1 Million
LENGTH		
12 in	= 1 ft	12 in/ft
3 ft	= 1 yd	3 ft/yd
5280 ft	= 1 mi	5280 ft/mi
AREA		
144 sq in	= 1 sq ft	144 sq in/sq ft
43,560 sq ft	= 1 acre	43,560 sq ft/ac
VOLUME		
7.48 gal	= 1 cu ft	7.48 gal/cu ft
1000 m*L*	= 1 liter	1000 m*L*/*L*
3.785 *L*	= 1 gal	3.785 *L*/gal
231 cu in	= 1 gal	231 cu in/gal
WEIGHT		
1000 mg	= 1 gm	1000 mg/gm
1000 gm	= 1 kg	1000 gm/kg
454 gm	= 1 lb	454 gm/lb
2.2 lbs	= 1 kg	2.2 lbs/kg
POWER		
0.746 kw	= 1 HP	0.746 kw/HP
DENSITY		
8.34 lbs	= 1 gal	8.34 lbs/gal
62.4 lbs	= 1 cu ft	62.4 lbs/cu ft
DOSAGE		
17.1 mg/*L*	= 1 grain/gal	17.1 mg/*L*/gpg
64.7 grains	= 1 mg	64.7 grains/mg
PRESSURE		
2.31 ft water	= 1 psi	2.31 ft water/psi
0.433 psi	= 1 ft water	0.433 psi/ft water
1.133 ft water	= 1 in Mercury	1.133 ft water/in Mercury
FLOW		
694 GPM	= 1 MGD	694 GPM/MGD
1.55 CFS	= 1 MGD	1.55 CFS/MGD
TIME		
60 sec	= 1 min	60 sec/min
60 min	= 1 hr	60 min/hr
24 hr	= 1 day	24 hr/day

A.11 BASIC FORMULAS

FLOWS

1. $$\text{Flow, MGD} = \frac{(\text{Flow, GPM})(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}{1{,}000{,}000}$$

or $$\text{Flow, GPM} = \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1\text{ Million})(60\text{ min/hr})(24\text{ hr/day})}$$

CHEMICAL DOSES

Chemical Feeder Setting

2. $$\text{Chemical Dose, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

3. $$\text{Chemical Feeder Setting, m}L\text{/min} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(3.785\ L\text{/gal})(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\text{ hr/day})(60\text{ min/hr})(1\text{ Million})}$$

4. $$\text{Chemical Feeder Setting, gal/day} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(8.34\text{ lbs/gal})}{\text{Liquid Alum, lbs/gal}}$$

Calibration of a Dry Chemical Feeder

5. $$\text{Chemical Feed, lbs/day} = \frac{\text{Chemical Applied, lbs}}{\text{Length of Application, day}}$$

Calibration of a Solution Chemical Feeder
(Chemical Feed Pump or a Hypochlorinator)

6. $$\text{Chemical Feed, lbs/day} = \frac{(\text{Chem Conc, mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

7. $$\text{Chemical Feed, GPM} = \frac{\text{Chemical Used, gal}}{(\text{Time, hr})(60\text{ min/hr})}$$

or $$= \frac{(\text{Chemical Feed Rate, m}L\text{/sec})(60\text{ sec/min})}{3785\text{ m}L\text{/gal}}$$

8a. $$\text{Chemical Solution, gal} = \frac{(\text{Chemical Solution, \%})(8.34\text{ lbs/gal})}{100\%}$$

8b. $$\text{Feed Pump, GPD} = \frac{\text{Chemical Feed, lbs/day}}{\text{Chemical Solution, lbs/gal}}$$

8c. $$\text{Feeder Setting, \%} = \frac{(\text{Desired Feed Pump, GPD})(100\%)}{\text{Maximum Feed Pump, GPD}}$$

RESERVOIR MANAGEMENT AND INTAKE STRUCTURES

9. $$\text{Reservoir Volume, ac/ft} = \frac{\text{Reservoir Volume, cu ft}}{43{,}560\text{ sq ft/ac}}$$

10. $$\text{Reservoir Volume, gal} = (\text{Volume, ac ft})(43{,}560\text{ sq ft/ac})(7.48\text{ gal/cu ft})$$

11. $$\text{Chemical Dose, lbs} = (\text{Surface Area, ac})(\text{Dose, lbs/ac})$$

12. $$\text{Chemical Dose, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})$$

13. $$\text{Chemical, lbs} = \frac{(\text{Vol, M Gal})(\text{Dose, mg}/L)(8.34\text{ lbs/gal})(100\%)}{\text{Chemical, \%}}$$

COAGULATION AND FLOCCULATION

14. $$\text{Polymer, lbs} = \frac{(\text{Polymer Solution, gal})(8.34\text{ lbs/gal})(\text{Polymer, \%})(\text{Sp Gr})}{100\%}$$

15. $$\text{Dose, mg}/L = \frac{\text{Chemical Feed, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

16. $$\text{Polymer, \%} = \frac{(\text{Dry Polymer, lbs})(100\%)}{(\text{Dry Polymer, lbs} + \text{Water, lbs})}$$

17. $$\text{Liquid Polymer, gal} = \frac{(\text{Polymer Solution, \%})(\text{Volume of Solution, gal})}{\text{Liquid Polymer, \%}}$$

SEDIMENTATION

18. $$\text{Detention Time, hr} = \frac{(\text{Volume, gal})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{(\text{Volume, cu ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Flow, gal/day}}$$

19. $$\text{Overflow Rate, GPM/sq ft or Surface Loading} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

20. $$\text{Mean Flow Velocity, ft/min} = \frac{\text{Flow, GPM}}{(\text{Cross-Sectional Area, sq ft})(7.48\text{ gal/cu ft})}$$

21. $$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Weir Length, ft}}$$

FILTRATION

22. $$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

23. $$\text{Velocity, ft/min} = \frac{\text{Water Drop, ft}}{\text{Time, min}}$$

24. Flow, cu ft/min = (Area, sq ft)(Velocity, ft/min)

25. Flow, gal/min = (Flow, cu ft/min)(7.48 gal/cu ft)

OR

26. $$\text{Flow, gal/min} = \frac{\text{Total Flow, gal}}{(\text{Filter Run, hr})(60\text{ min/hr})}$$

27. Uniform Filter Run Volume (UFRV)

$$\text{UFRV, gal/sq ft} = \frac{\text{Volume Filtered, gal}}{\text{Filter Surface Area, sq ft}}$$

28. UFRV, gal/sq ft = (Filtration Rate, GPM/sq ft)(Filter Run, hr)(60 min/hr)

29. Backwash Flow, GPM = (Filter Area, sq ft)(Backwash Rate, GPM/sq ft)

30. $$\text{Backwash, in/min} = \frac{(\text{Backwash, GPM/sq ft})(12\text{ in/ft})}{7.48\text{ gal/cu ft}}$$

31. Backwash Water, gal = (Backwash Flow, GPM)(Backwash Time, min)

32. $$\text{Backwash, \%} = \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}$$

DISINFECTION

33. $$\text{Chlorine Dose, mg/}L = \frac{\text{Chlorine Feed, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}$$

34. Chlorine Demand, mg/*L* = Chlorine Dose, mg/*L* − Chlorine Residual, mg/*L*

35. $$\text{Chlorine, lbs} = (\text{Hypochlorite, gal})(8.34\text{ lbs/gal})\left(\frac{\text{Hypochlorite, \%}}{100\%}\right)$$

36. $$\text{Hypochlorite Flow, GPD} = \frac{(\text{Container Area, sq ft})(\text{Drop, ft})(7.48\text{ gal/cu ft})(24\text{ hr/day})}{\text{Time, hr}}$$

37. $$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, gal/day})(8.34\text{ lbs/gal})}$$

38. $$\text{Water Added, gal (to hypochlorite solution)} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

CORROSION CONTROL

39. $$\text{D. F. I.} = \frac{[\text{Ca}^{2+}][\text{CO}_3{}^{2-}]}{K'_{sp} \times 10^{10}}$$

40. $\text{pH}_s = A + B - \log(\text{Ca}^{2+}) - \log(\text{Alky})$

41. $\text{Langelier Index} = \text{pH} - \text{pH}_s$

PLANT OPERATION

42. $$\text{Average Chemical Use, lbs/day} = \frac{\text{Sum of Chemical Used Each Day, lbs}}{\text{Total Time, days}}$$

43. $$\text{Supply of Chlorine, days} = \frac{(\text{Cylinder Wt, lbs/cyl})(\text{No. of Cylinders})}{\text{Ave. Use, lbs/day}}$$

LABORATORY PROCEDURES

44. $\text{Temperature, °C} = \frac{5}{9}(\text{°F} - 32\text{°F})$

45. $\text{Temperature, °F} = \frac{9}{5}(\text{°C}) + 32\text{°F}$

46. Drop-dilution Chlorine Residual

$$\text{Actual Chlorine Residual, mg/}L = \frac{(\text{Chlorine Residual, mg/}L)(\text{Distilled Water, m}L)}{(\text{Sample Volume, drops})(0.05\text{ m}L\text{/drop})}$$

47. $$\text{Mean or Average} = \frac{\text{Sum of Values or Measurements}}{\text{Number of Values or Measurements}}$$

48. Median = Middle Value of a Group of Data

49. $\text{Geometric Mean} = [(X_1)(X_2)(X_3)\ \ldots\ldots\ (X_n)]^{1/n}$

A.12 HOW TO USE THE BASIC FORMULAS

One clever way of using the basic formulas is to use the Davidson[1] Pie Method. To apply this method to the first basic formula,

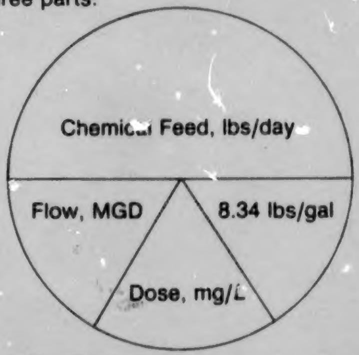
1. Chemical Feeder, lbs/day = (Flow, MGD)(Dose, mg/*L*)(8.34 lbs/gal)

(a) Draw a circle and draw a horizontal line through the middle of the circle;

(b) Write the Chemical Feed, lbs/day in the top half;

(c) Divide the bottom half into three parts; and

(d) Write Flow, MGD; Dose, mg/*L*, and 8.34 lbs/gal in the other three parts.



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[1] Gerald Davidson, Manager, Clear Lake Oaks Water District, Clear Lake Oaks, California.

If you want to find the Chemical Feed, lbs/day, cover up the Chemical Feed, and what is left uncovered will give you the correct formula.

$$2.\ \text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

If you know the chlorinator setting in pounds per day and the flow in MGD and would like to know the dose in mg/*L*, cover up the Dose, mg/*L*, and what is left uncovered will give you the correct formula.

$$3.\ \text{Dose, mg}/L = \frac{\text{Chemical Feed, lbs/day}}{(\text{Flow, MGD})(8.34\ \text{lbs/gal})}$$

Another approach to using the basic formulas is to memorize the basic formula, for example the detention time formula.

$$4.\ \text{Detention Time, hr} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

This formula works fine to solve for the detention time when the Tank Volume, gal, and Flow, gal/day, are given.

If you wish to determine the Flow, gal/day, when the Detention Time, hr, and Tank Volume, gal, are given, you must change the basic formula. You want the Flow, gal/day, on the left of the equal sign and everything else on the right of the equal sign. This is done by moving the terms diagonally (from top to bottom or from bottom to top) past the equal sign.

$$4.\ \boxed{\text{Detention Time, hr}} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\boxed{\text{Flow, gal/day}}}$$

or

$$\text{Flow, gal/day} = \frac{(\text{Tank Volume, gal})(24\ \text{hr/day})}{\text{Detention Time, hr}}$$

This same approach can be used if the Tank Volume, gal, was unknown and the Detention Time, hr, and Flow, gal/day, were given. We want Tank Volume, gal, on one side of the equation and everything else on the other side.

$$4.\ \text{Detention Time, hr} = \frac{(\text{Tank Volume, gal})\boxed{(24\ \text{hr/day})}}{\boxed{\text{Flow, gal/day}}}$$

To Top

To Bottom

or

$$\frac{(\text{Detention Time, hr})(\text{Flow, gal/day})}{24\ \text{hr/day}} = \text{Tank Volume, gal}$$

or

$$\text{Tank Volume, gal} = \frac{(\text{Detention Time, hr})(\text{Flow, gal/day})}{24\ \text{hr/day}}$$

One more check is to be sure the units in the rearranged formula cancel out correctly.

For additional information on the use of the basic formulas, refer to Sections:

A.91, "Selection of Formula,"

A.92, "Arrangement of Formula,"

A.93, "Unit Conversions," and

A.94, "Calculations."

A.13 TYPICAL WATER TREATMENT PLANT PROBLEMS (ENGLISH SYSTEM)

A.130 Flows

EXAMPLE 1

Convert a flow of 800 gallons per minute to million gallons per day.

Known	Unknown
Flow, GPM = 800 GPM	Flow, MGD

Convert flow from 800 GPM to MGD.

$$\begin{aligned}\text{Flow, MGD} &= \frac{(\text{Flow, GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}\\ &= \frac{(800\ \text{GPM})(1\ \text{Million})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000}\\ &= 1.15\ \text{MGD}\end{aligned}$$

NOTE: When we multiply an equation by $\frac{1\ \text{Million}}{1{,}000{,}000}$ we do not change anything except the units. This is just like multiplying an equation by 12 inches/feet or 60 min/hr; all we are doing is changing units.

A.131 Chemical Doses

EXAMPLE 2

Determine the chlorinator setting in pounds per 24 hours to treat a flow of 2 MGD with a chlorine dose of 3.0 mg/*L*.

Known		Unknown
Flow, MGD	=2 MGD	Chlorinator Setting, lbs/24 hours
Chlorine, Dose, mg/*L*	=3.0 mg/*L*	

Determine the chlorinator setting in pounds per 24 hours or pounds per day.

$$\begin{aligned}\text{Chemical Feed, lbs/day} &= (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})\\ &= (2\ \text{MGD})(3.0\ \text{mg}/L)(8.34\ \text{lbs/gal})\\ &= 50\ \text{lbs/day}\end{aligned}$$

EXAMPLE 3

The optimum liquid alum dose from the jar tests is 12 mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the plant flow is 4.7 MGD. The liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of liquid solution.

Known		Unknown
Alum Dose, mg/*L*	=12 mg/*L*	Chemical Feeder Setting, m*L*/min
Flow, MGD	= 4.7 MGD	
Liquid Alum, mg/m*L*	=642.3 mg/m*L*	

Calculate the liquid alum chemical feeder setting in milliliters per minute.

$$\begin{aligned}\text{Chemical Feeder Setting, m}L\text{/min} &= \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}\\ &= \frac{(4.7\ \text{MGD})(12\ \text{mg}/L)(3.785\ L/\text{gal})(1{,}000{,}000)}{(642.3\ \text{mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}\\ &= 231\ \text{m}L/\text{min}\end{aligned}$$

EXAMPLE 4

The optimum liquid alum dose from the jar tests is 12 mg/*L*. Determine the setting on the liquid alum chemical feeder in gallons per day when the flow is 4.7 MGD. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

Known	Unknown
Alum Dose, mg/*L* = 12 mg/*L*	Chemical Feeder Setting, GPM
Flow, MGD = 4.7 MGD	
Liquid Alum, lbs/gal = 5.36 lbs/gal	

Calculate the liquid alum chemical feeder setting in gallons per day.

$$\text{Chemical Feeder Setting, GPD} = \frac{(\text{Flow, MGD})(\text{Alum Dose, mg}/L)(8.34\text{ lbs/gal})}{\text{Liquid Alum, lbs/gal}}$$

$$= \frac{(4.7\text{ MGD})(12\text{ mg}/L)(8.34\text{ lbs/gal})}{5.36\text{ lbs/gal}}$$

$$= 88\text{ GPD}$$

EXAMPLE 5

Determine the actual chemical feed in pounds per day from a dry chemical feeder. A bucket placed under the chemical feeder weighed 0.3 pounds empty and 2.1 pounds after 30 minutes.

Known	Unknown
Empty Bucket, lbs = 0.3 lbs	Chemical Feed, lbs/day
Full Bucket, lbs = 2.1 lbs	
Time to Fill, min = 30 min	

Determine the chemical feed in pounds of chemical applied per day.

$$\text{Chemical Feed, lbs} = \frac{\text{Chemical Applied, lbs}}{\text{Length of Application, day}}$$

$$= \frac{(2.1\text{ lbs} - 0.3\text{ lbs})(60\text{ min/hr})(24\text{ hr/day})}{(30\text{ min})}$$

$$= 86\text{ lbs/day}$$

EXAMPLE 6

Determine the chemical feed in pounds of polymer per day from a chemical feed pump. The polymer solution is 1.5 percent or 15,000 mg polymer per liter. Assume a specific gravity of the polymer solution of 1.0. During a test run the chemical feed pump delivered 800 m*L* of polymer solution during five minutes.

Known	Unknown
Polymer Solution, % = 1.5%	Polymer Feed, lbs/day
Polymer Conc, mg/*L* = 15,000 mg/*L*	
Polymer Sp Gr = 1.0	
Volume Pumped, m*L* = 800 m*L*	
Time Pumped min = 5 min	

Calculate the polymer fed by the chemical feed pump in pounds of polymer per day.

$$\text{Polymer Feed, lbs/day} = \frac{(\text{Poly Conc, mg}/L)(\text{Vol Pumped, m}L)(60\text{ min/hr})(24\text{ hr/day})}{(\text{Time Pumped, min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= \frac{(15{,}000\text{ mg}/L)(800\text{ m}L)(60\text{ min/hr})(24\text{ hr/day})}{(5\text{ min})(1000\text{ m}L/L)(1000\text{ mg/gm})(454\text{ gm/lb})}$$

$$= 7.6\text{ lbs polymer/day}$$

EXAMPLE 7

A small chemical feed pump lowered the chemical solution in a three-foot diameter tank one foot and seven inches during an eight-hour period. Estimate the flow delivered by the pump in gallons per minute and gallons per day.

Known	Unknown
Tank Diameter, ft = 3 ft	Flow, GPM
Chemical Drop, ft = 1 ft 7 in	Flow, GPD
Time, hr = 8 hr	

1. Convert the tank drop from one foot seven inches to feet.

$$\text{Tank Drop, ft} = 1\text{ ft} + 7\text{ inches}$$

$$= 1\text{ ft} + \frac{7\text{ in}}{12\text{ in/ft}}$$

$$= 1\text{ ft} + 0.58\text{ ft}$$

$$= 1.58\text{ ft}$$

2. Determine the gallons of water pumped.

$$\text{Volume Pumped, gal} = (\text{Area, sq ft})(\text{Drop, ft})(7.48\text{ gal/cu ft})$$

$$= (0.785)(3\text{ ft})^2(1.58\text{ ft})(7.48\text{ gal/cu ft})$$

$$= 83.5\text{ gal}$$

3. Estimate the flow delivered by the pump in gallons per minute and gallons per day.

$$\text{Flow, GPM} = \frac{\text{Volume Pumped, gal}}{(\text{Time, hr})(60\text{ min/hr})}$$

$$= \frac{83.5\text{ gal}}{(8\text{ hr})(60\text{ min/hr})}$$

$$= 0.17\text{ GPM}$$

or

$$\text{Flow, GPD} = \frac{(\text{Volume Pumped, gal})(24\text{ hr/day})}{\text{Time, hr}}$$

$$= \frac{(83.5\text{ gal})(24\text{ hr/day})}{8\text{ hr}}$$

$$= 250\text{ GPD}$$

EXAMPLE 8

Determine the settings in percent stroke on a chemical feed pump for various doses of a chemical in milligrams per liter. (The chemical could be chlorine, polymer, potassium permanganate or any other chemical solution fed by a pump.) The pump delivering the water to be treated pumps at a flow rate of 400 GPM. The solution strength of the chemical being pumped is 4.8 percent. The chemical feed pump has a maximum capacity of 92 gallons per day at a setting of 100 percent capacity.

Known	Unknown
Pump Flow, GPM = 400 GPM	Setting, % stroke for various doses in mg/*L*
Solution Strength, % = 4.8%	
Feed Pump, GPD (100% stroke) = 92 GPD	

1. Convert the pump flow from gallons per minute to million gallons per day.

$$\text{Pump Flow, MGD} = (\text{Pump Flow, GPM})(60\ \text{min/hr})(24\ \text{hr/day})$$

$$= (400\ \text{gal/min})(60\ \text{min/hr})(24\ \text{hr/day})$$

$$= 576{,}000\ \text{gal/day}$$

$$= 0.576\ \text{MGD}$$

2. Change the chemical solution strength from a percent to pounds of chemical per gallon of solution. A 4.8 percent solution means we have 4.8 pounds of chemical in a solution of water and chemical weighing 100 pounds.

$$\text{Chemical Solution, lbs/gal} = \frac{4.8\ \text{lbs chemical}}{100\ \text{lbs of chemical and water}}$$

$$= \frac{(4.8\ \text{lbs})(8.34\ \text{lbs/gal})}{100\ \text{lbs}}$$

$$= 0.4\ \text{lbs chemical/gallon solution}$$

3. Calculate the chemical feed in pounds per day for a chemical dose of 0.5 milligrams per liter. We are going to assume various chemical doses of 0.5, 1.0, 1.5, 2.0, 2.5 mg/*L* and upward so that if we know the desired chemical dose, we can easily determine the setting (percent stroke) on the chemical feed pump.

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34\ \text{lbs/gal})$$

$$= (0.576\ \text{MGD})(0.5\ \text{mg}/L)(8.34\ \text{lbs/gal})$$

$$= 2.4\ \text{lbs/day}$$

4. Determine the desired flow from the chemical feed pump in gallons per day.

$$\text{Feed Pump, GPD} = \frac{\text{Chemical Feed, lbs/day}}{\text{Chemical Solution, lbs/gal}}$$

$$= \frac{2.4\ \text{lbs/day}}{0.4\ \text{lbs/gal}}$$

$$= 6\ \text{GPD}$$

5. Determine the setting on the chemical feed pump as a percent. In this case we want to know the setting as a percent of the pump stroke.

$$\text{Setting, \%} = \frac{(\text{Desired Feed Pump, GPD})(100\%)}{\text{Maximum Feed Pump, GPD}}$$

$$= \frac{(6\ \text{GPD})(100\%)}{92\ \text{GPD}}$$

$$= 6.5\%$$

6. If we changed the chemical dose in Step 3 from 0.5 mg/*L* to 1.0 mg/*L* and other higher doses and repeated the remainder of the steps, we could calculate the data in Table A.1.

7. Plot the data in Table A.1 (Chemical Dose, mg/*L* vs. Pump Setting, % stroke) to obtain Figure A.3. Only three points were needed since the data plotted a straight line. For any desired chemical dose in milligrams per liter, you can use Figure A.3 to determine the necessary chemical feed pump setting.

TABLE A.1 SETTINGS FOR CHEMICAL FEED PUMP

PUMP FLOW, GPM =400 GPM

SOLUTION STRENGTH, % =4.8%

Chemical Dose, mg/*L*	Chemical Feed, lbs/day	Feed Pump, GPD	Pump Setting % stroke
0.5	2.4	6.0	6.5
1.0	4.8	12.0	13.0
1.5	7.2	18.0	19.5
2.0	9.6	24.0	26.1
2.5	12.0	30.0	32.6
3.0	14.4	36.0	39.1
3.5	16.8	42.0	45.6
4.0	19.2	48.0	52.2
4.5	21.6	54.0	58.7
5.0	24.0	60.0	65.2
5.5	26.4	66.0	71.7
6.0	28.8	72.0	78.2
6.5	31.2	78.0	84.8
7.0	33.6	84.0	91.3
7.5	36.0	90.0	97.8

A.132 Reservoir Management and Instake Structures

EXAMPLE 9

The volume of a reservoir is estimated to be 581,000 cubic feet. Estimate the volume in acre feet.

Known	Unknown
Reservoir Vol, cu ft =581,000 cu ft	Reservoir Vol, ac ft

Estimate the reservoir volume in acre feet.

$$\text{Reservoir Vol, ac ft} = \frac{\text{Reservoir Vol, cu ft}}{43{,}560\ \text{sq ft/ac}}$$

$$= \frac{581{,}000\ \text{cu ft}}{43{,}560\ \text{sq ft/ac}}$$

$$= 13.3\ \text{ac ft}$$

EXAMPLE 10

A reservoir has a volume of 6.8 acre feet. What is the reservoir volume in gallons and million gallons?

Known	Unknown
Reservoir Vol, ac ft =6.8 ac ft	1. Reservoir Vol, gal 2. Reservoir Vol, MG

Convert reservoir volume from acre feet to gallons and million gallons.

$$\text{Reservoir Vol, gal} = (\text{Volume, ac ft})(43{,}560\ \text{sq ft/ac})(7.48\ \text{gal/cu ft})$$

$$= (6.8\ \text{ac ft})(43{,}560\ \text{sq ft/ac})(7.48\ \text{gal/cu ft})$$

$$= 2{,}215{,}636\ \text{gal}$$

$$= 2.2\ \text{M Gal}$$

EXAMPLE 11

A reservoir has a surface area of 51,200 square feet and the desired dose of copper sulfate is six pounds per acre. How many pounds of copper sulfate will be needed?

Known	Unknown
Surface Area, sq ft =51,200 sq ft	Copper Sulfate, lbs
Dose, lbs/ac =6 lbs/ac	

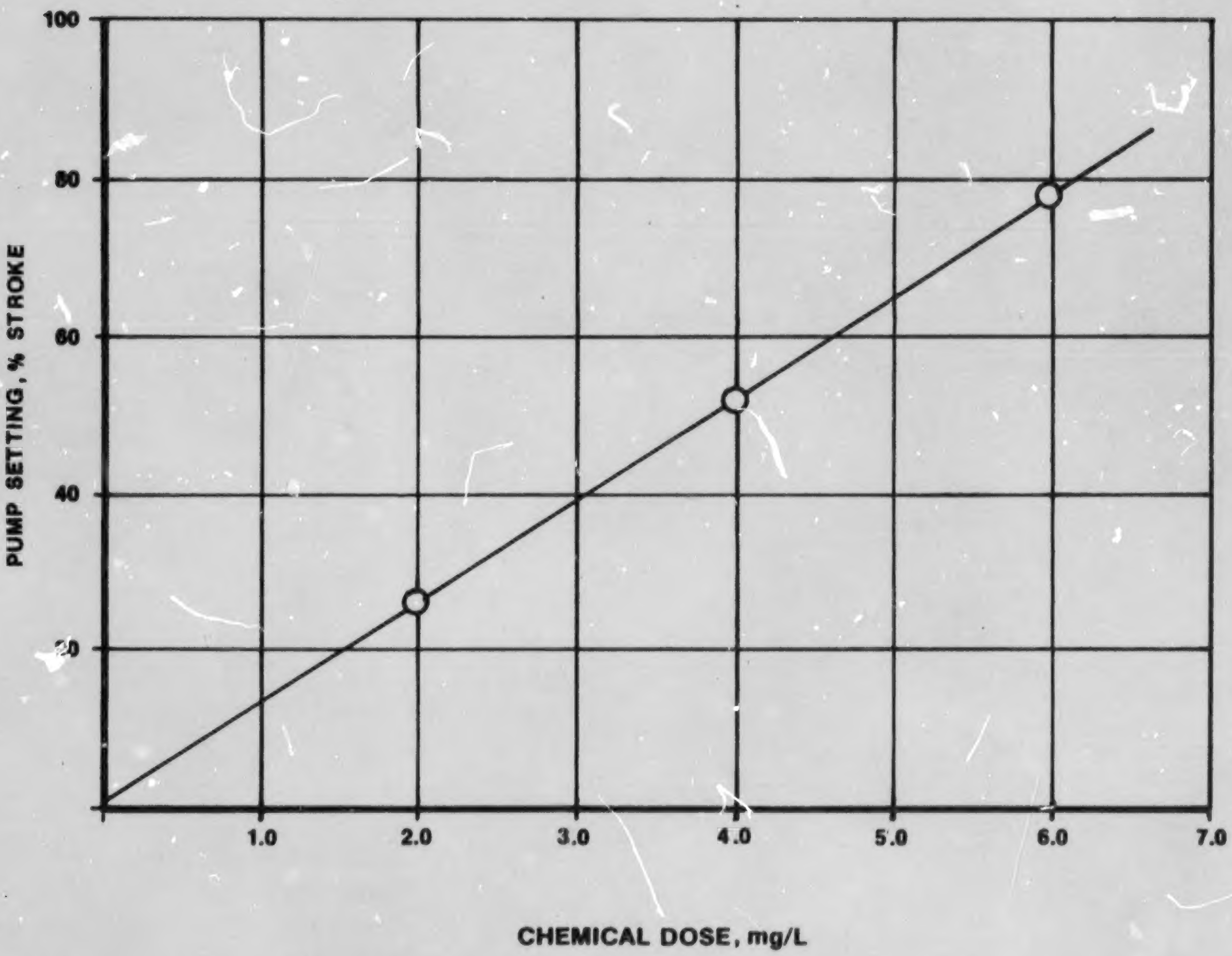


Fig. A.3 Chemical feed pump settings for various chemical doses

1. Convert the surface area from square feet to acres.

$$\text{Surface Area, ac} = \frac{\text{Surface Area, sq ft}}{43{,}560 \text{ sq ft/ac}}$$

$$= \frac{51{,}200 \text{ sq ft}}{43{,}560 \text{ sq ft/ac}}$$

$$= 1.18 \text{ ac}$$

2. Calculate the pounds of copper sulfate needed.

$$\text{Copper Sulfate, lbs} = (\text{Surface Area, ac})(\text{Dose, lbs/ac})$$

$$= (1.18 \text{ ac})(6 \text{ lbs/ac})$$

$$= 7.1 \text{ lbs copper sulfate}$$

EXAMPLE 12

The volume of a reservoir is estimated to be five million gallons. The desired chemical dose is 0.5 mg/*L*. Estimate the chemical dose in pounds.

Known		Unknown
Reservoir Vol, M Gal	=5 M Gal	Chemical Dose, lbs
Chemical Dose, mg/*L*	=0.5 mg/*L*	

Estimate the chemical dose in pounds.

$$\text{Chemical Dose, lbs} = (\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

$$= (5 \text{ M Gal})(0.5 \text{ mg}/L)(8.34 \text{ lbs/gal})$$

$$= 20.9 \text{ lbs}$$

EXAMPLE 13

The volume of a reservoir is estimated to be 581,000 cubic feet. The desired dose of copper is 0.5 mg/*L* and the copper content of the copper sulfate to be used is 25 percent. How many pounds of copper sulfate will be needed?

Known		Unknown
Reservoir Volume, cu ft	=581,000 cu ft	Copper Sulfate, lbs
Copper Dose, mg/*L*	=0.5 mg/*L*	
Copper, %	=25%	

1. Convert the reservoir volume from cubic feet to million gallons.

$$\text{Reservoir Volume, M Gal} = \frac{(\text{Reservoir Vol, cu ft})(7.48 \text{ gal/cu ft})(1 \text{ Million})}{1{,}000{,}000}$$

$$= \frac{(581{,}000 \text{ cu ft})(7.48 \text{ gal/cu ft})(1 \text{ Million})}{1{,}000{,}000}$$

$$= 4.35 \text{ M Gal}$$

2. Calculate the pounds of copper sulfate that will be needed.

$$\text{Copper Sulfate, lbs} = \frac{(\text{Volume, M Gal})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})(100\%)}{\text{Copper, \%}}$$

$$= \frac{(4.35 \text{ M Gal})(0.5 \text{ mg}/L)(8.34 \text{ lbs/gal})(100\%)}{25\%}$$

$$= 72.6 \text{ lbs copper sulfate}$$

A.133 Coagulation and Flocculation

EXAMPLE 14

A polymer feed pump delivers a flow of 200 gallons per day containing a five percent polymer solution with a specific gravity of 1.02. Estimate the polymer delivered in pounds per day.

Known		Unknown
Flow, gal/day	=200 gal/day	Polymer, lbs/day
Flow, MGD	=0.0002 MGD	
Polymer, %	=5%	
Polymer, mg/*L*	=50,000 mg/*L*	
Sp Gr	=1.02	

Estimate the polymer delivered in pounds per day.

Solution 1

$$\text{Polymer, lbs/day} = \frac{(\text{Polymer Solution, gal/day})(8.34 \text{ lbs/gal})(\text{Polymer, \%})(\text{Sp Gr})}{100\%}$$

$$= \frac{(200 \text{ gal/day})(8.34 \text{ lbs/gal})(5\%)(1.02)}{100\%}$$

$$= 85 \text{ lbs polymer/day}$$

Solution 2

$$\text{Polymer, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})(\text{Sp Gr})$$

$$= (0.0002 \text{ MGD})(50{,}000 \text{ mg}/L)(8.34 \text{ lbs/gal})(1.02)$$

$$= 85 \text{ lbs polymer/day}$$

SAME ANSWER!

EXAMPLE 15

Estimate the actual dose in milligrams per liter if a plant treats a raw water with a flow of 1.8 MGD. The alum feed rate is 135 pounds per day.

Known		Unknown
Flow, MGD	=1.8 MGD	Alum Dose, mg/*L*
Alum Feed, lbs/day	=135 lbs/day	

Calculate the alum dose in milligrams per liter.

BASIC EQUATION

$$\text{Chemical Feed, lbs/day} = (\text{Flow, MGD})(\text{Dose, mg}/L)(8.34 \text{ lbs/gal})$$

OR

$$\text{Alum Dose, mg}/L = \frac{\text{Chemical Feed, lbs/day}}{(\text{Flow, MGD})(8.34 \text{ lbs/gal})}$$

$$= \frac{135 \text{ lbs/day}}{(1.8 \text{ MGD})(8.34 \text{ lbs/gal})}$$

$$= 9.0 \text{ mg}/L$$

EXAMPLE 16

Determine the strength of a polymer solution as a percent if 80 grams (80 g/454 g/lb = 0.176 lbs) of dry polymer are mixed with four gallons of water.

Known		Unknown
Dry Polymer, lbs	=0.176 lbs	Polymer Solution, %
Volume Water, gal	=4 gal	

1. Convert the four gallons of water to pounds.

$$\text{Water, lbs} = (\text{Volume Water, gal})(8.34 \text{ lbs/gal})$$

$$= (4 \text{ gal})(8.34 \text{ lbs/gal})$$

$$= 33.36 \text{ lbs}$$

2. Calculate the polymer solution as a percent.

$$\text{Polymer, \%} = \frac{(\text{Dry Polymer, lbs})(100\%)}{(\text{Dry Polymer, lbs} + \text{Water, lbs})}$$

$$= \frac{(0.176 \text{ lbs})(100\%)}{(0.176 \text{ lbs} + 33.36 \text{ lbs})}$$

$$= 0.52\%$$

EXAMPLE 17

Liquid polymer is supplied to a water treatment plant as a ten percent solution. How many gallons of liquid polymer should be mixed in a tank with water to produce 200 gallons of 0.6 percent polymer solution?

Known	Unknown
Liquid Polymer, % = 10%	Volume of Liquid Polymer, gal
Polymer Solution, % = 0.6%	
Volume of Polymer Solution, gal = 200 gal	

Calculate the volume of liquid polymer in gallons.

$$\text{Liquid Polymer, gal} = \frac{(\text{Polymer Solution, \%})(\text{Volume of Solution, gal})}{\text{Liquid Polymer, \%}}$$

$$= \frac{(0.6\ \%)(200 \text{ gal})}{10\%}$$

$$= 12 \text{ gallons}$$

A.134 Sedimentation

EXAMPLE 18

Estimate the detention time in hours for a 30-foot diameter circular clarifier when the flow is 0.5 MGD. The clarifier is eight feet deep.

Known	Unknown
Diameter, ft = 30 ft	Detention Time, hr
Depth, ft = 8 ft	
Flow, MGD = 0.5 MGD	
Flow, gal/day = 500,000 gal/day	

1. Calculate the clarifier volume in cubic feet.

$$\text{Volume, cu ft} = (\text{Area, sq ft})(\text{Depth, ft})$$

$$= (0.785)(30 \text{ ft})^2(8 \text{ ft})$$

$$= 5652 \text{ cu ft}$$

2. Estimate the detention time of the clarifier in hours.

$$\text{Detention Time, hr} = \frac{(\text{Volume, cu ft})(7.48 \text{ gal/cu ft})(24 \text{ hr/day})}{\text{Flow, gal/day}}$$

$$= \frac{(5652 \text{ cu ft})(7.48 \text{ gal/cu ft})(24 \text{ hr/day})}{500{,}000 \text{ gal/day}}$$

$$= 2.0 \text{ hr}$$

EXAMPLE 19

Estimate the overflow rate in gallons per minute per square foot for a rectangular sedimentation basin 20-feet wide and 40-feet long when the flow is 0.5 MGD.

Known	Unknown
Width, ft = 20 ft	Overflow Rate, GPM/sq ft
Length, ft = 40 ft	
Flow, MGD = 0.5 MGD	

1. Determine the surface area of the basin in square feet.

$$\text{Surface Area, sq ft} = (\text{Length, ft})(\text{Width, ft})$$

$$= (40 \text{ ft})(20 \text{ ft})$$

$$= 800 \text{ sq ft}$$

2. Convert the flow from million gallons per day to gallons per minute.

$$\text{Flow, GPM} = \frac{(\text{Flow, MGD})(1{,}000{,}000)}{(1 \text{ Million})(60 \text{ min/hr})(24 \text{ hr/day})}$$

$$= \frac{(0.5 \text{ MGD})(1{,}000{,}000)}{(1 \text{ Million})(60 \text{ min/hr})(24 \text{ hr/day})}$$

$$= 347 \text{ GPM}$$

3. Estimate the overflow rate in gallons per minute per square foot of surface area.

$$\text{Overflow Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$= \frac{347 \text{ GPM}}{800 \text{ sq ft}}$$

$$= 0.43 \text{ GPM/sq ft}$$

EXAMPLE 20

Estimate the flow velocity in feet per minute through a rectangular sedimentation basin 20-feet wide and eight-feet deep when the flow is 350 GPM.

Known	Unknown
Width, ft = 20 ft	Flow Velocity, ft/min
Depth, ft = 8 ft	
Flow, GPM = 350 GPM	

Estimate the flow velocity in feet per minute.

$$\text{Flow Velocity, ft/min} = \frac{\text{Flow, GPM}}{(\text{Cross-Sectional Area, sq ft})(7.48 \text{ gal/cu ft})}$$

$$= \frac{350 \text{ GPM}}{(20 \text{ ft})(8 \text{ ft})(7.48 \text{ gal/cu ft})}$$

$$= 0.29 \text{ ft/min}$$

EXAMPLE 21

Estimate the weir loading in gallons per minute per foot of weir length for a 30-foot diameter circular clarifier treating a flow of 350 GPM. The weir is located on the water edge of the clarifier.

Known	Unknown
Weir Diameter, ft = 30 ft	Weir Loading, GPM/ft
Flow, GPM = 350 GPM	

Calculate the weir length in feet.

$$\text{Weir Length, ft} = \pi\ (\text{Diameter, ft})$$

$$= 3.14\ (30 \text{ ft})$$

$$= 94.2 \text{ ft}$$

Estimate the weir loading in gallons per minute per foot of weir.

$$\text{Weir Loading, GPM, ft} = \frac{\text{Flow, GPM}}{\text{Weir Length, ft}}$$

$$= \frac{350 \text{ GPM}}{94.2 \text{ ft}}$$

$$= 3.7 \text{ GPM/ft}$$

A.135 Filtration

EXAMPLE 22

A 25-foot wide by 30-foot long rapid sand filter treats a flow of 2000 gallons per minute. Calculate the filtration rate in gallons per minute per square foot of filter area.

Known	Unknown
Width, ft =25 ft	Filtration Rate, GPM/sq ft
Length, ft =30 ft	
Flow, GPM =2000 GPM	

Calculate the filtration rate in gallons per minute per square foot of filter surface area.

$$\text{Filtration Rate, GPM/sq ft} = \frac{\text{Flow, GPM}}{\text{Surface Area, sq ft}}$$

$$= \frac{2000\text{ GPM}}{(25\text{ ft})(30\text{ ft})}$$

$$= 2.7\text{ GPM/sq ft}$$

EXAMPLE 23

With the inflow water shut off to a rapid sand filter, the water is observed to drop 20 inches in nine minutes. What is the velocity of the water dropping in feet per minute?

Known	Unknown
Water Drop, in =20 in	Velocity of Drop, ft/min
Time of Drop, min =9 min	

Calculate the velocity of the water drop in feet per minute.

$$\text{Velocity, ft/min} = \frac{\text{Water Drop, ft}}{\text{Time of Drop, min}}$$

$$= \frac{(20\text{ in})}{(12\text{ in/ft})(9\text{ min})}$$

$$= 0.185\text{ ft/min}$$

EXAMPLE 24

Estimate the flow through a rapid sand filter in cubic feet per minute when the velocity of the water dropping is 0.18 feet per minute and the filter is 25-feet wide and 30-feet long.

Known	Unknown
Velocity of Drop, ft/min =0.18 ft/min	Flow, cu ft/min
Width, ft =25 ft	
Length, ft =30 ft	

Estimate the flow through the filter in cubic feet per minute.

$$\text{Flow, cu ft/min} = (\text{Area, sq ft})(\text{Velocity, ft/min})$$

$$= (25\text{ ft})(30\text{ ft})(0.18\text{ ft/min})$$

$$= 135\text{ cu ft/min}$$

EXAMPLE 25

Calculate the flow through a rapid sand filter in gallons per minute when the flow is 135 cu ft per minute.

Known	Unknown
Flow, cu ft/min = 135 cu ft/min	Flow, GPM

Calculate the flow through the filter in gallons per minute.

$$\text{Flow, GPM} = (\text{Flow, cu ft/min})(7.48\text{ gal/cu ft})$$

$$= (135\text{ cu ft/min})(7.48\text{ gal/cu ft})$$

$$= 1010\text{ GPM}$$

EXAMPLE 26

Calculate the flow through a rapid sand filter in gallons per minute when 1.5 million gallons flowed through the filter during a 24-hour filter run.

Known	Unknown
Flow, M Gal =1.5 M Gal	Flow, GPM
Time, hr =24 hr	

Calculate the flow through the filter in gallons per minute.

$$\text{Flow, GPM} = \frac{\text{Total Flow, gal}}{(\text{Filter Run, hr})(60\text{ min/hr})}$$

$$= \frac{1{,}500{,}000\text{ gal}}{(24\text{ hr})(60\text{ min/hr})}$$

$$= 1040\text{ GPM}$$

EXAMPLE 27

Determine the Unit Filter Run Volume (UFRV) for a filter 20-feet long and 16-feet wide if the volume of water filtered between backwash cycles is 2.2 million gallons.

Known	Unknown
Length, ft =20 ft	UFRV, gal/cu ft
Width, ft =16 ft	
Volume Filtered, gal =2,200,000 gal	

Calculate the Unit Filter Run Volume in gallons per square foot of filter surface area.

$$\text{UFRV, gal/sq ft} = \frac{\text{Volume Filtered, gal}}{\text{Filter Surface Area, sq ft}}$$

$$= \frac{2{,}200{,}000\text{ gal}}{(20\text{ ft})(16\text{ ft})}$$

$$= 6{,}875\text{ gal/sq ft}$$

EXAMPLE 28

Determine the Unit Filter Run Volume (UFRV) for a filter if the filtration rate was 2.3 GPM/sq ft during a 46-hour filter run.

Known	Unknown
Filtration Rate, GPM/sq ft =2.3 GPM/sq ft	UFRV, gal/sq ft
Filter Run, hr =46 hr	

Calculate the Unit Filter Run Volume in gallons per square foot of filter surface area.

$$\text{UFRV, gal/sq ft} = (\text{Filtration Rate, GPM/sq ft})(\text{Filter Run, hr})(60\text{ min/hr})$$

$$= (2.3\text{ GPM/sq ft})(46\text{ hr})(60\text{ min/hr})$$

$$= 6348\text{ gal/sq ft}$$

EXAMPLE 29

Calculate the backwash flow required in gallons per minute to backwash a 25-foot wide by 30-foot long filter if the desired backwash flow rate is 20 gallons per minute per square foot.

Known	Unknown
Width, ft = 25 ft	Backwash Flow, GPM
Length, ft = 30 ft	
Backwash Rate, GPM/sq ft = 20 GPM/sq ft	

Calculate the backwash flow in gallons per minute.

$$\begin{aligned}\text{Backwash Flow, GPM} &= (\text{Filter Area, sq ft})(\text{Backwash Rate, GPM/sq ft})\\ &= (25\text{ ft})(30\text{ ft})(20\text{ GPM/sq ft})\\ &= 15{,}000\text{ GPM}\end{aligned}$$

EXAMPLE 30

Convert a filter backwash rate of 23 gallons per minute per square foot to inches per minute of rise.

Known	Unknown
Backwash, GPM/sq ft = 23 GPM/sq ft	Backwash, in/min

Convert the backwash rate from GPM/sq ft to inches/minute.

$$\begin{aligned}\text{Backwash, in/min} &= \frac{(\text{Backwash, GPM/sq ft})(12\text{ in/ft})}{7.48\text{ gal/cu ft}}\\ &= \frac{(23\text{ GPM/sq ft})(12\text{ in/ft})}{7.48\text{ gal/cu ft}}\\ &= 37\text{ in/min}\end{aligned}$$

EXAMPLE 31

Determine the volume or amount of water required to backwash a filter if the backwash flow rate is 9500 GPM when the backwash time is seven minutes.

Known	Unknown
Backwash Flow Rate, GPM = 9,500 GPM	Backwash Water, gallons
Backwash Time, min = 7 min	

Calculate the volume of backwash water required in gallons.

$$\begin{aligned}\text{Backwash Water gallons} &= (\text{Backwash Flow, GPM})(\text{Backwash Time, min})\\ &= (9{,}500\text{ gal/min})(7\text{ min})\\ &= 66{,}500\text{ gallons}\end{aligned}$$

EXAMPLE 32

During a filter run the total volume of water filtered was 13.0 million gallons. When the filter was backwashed, 66,500 gallons of water was used. Calculate the percent of the product or finished water used for backwashing.

Known	Unknown
Water Filtered, gal = 13,000,000 gal	Backwash, %
Backwash Water, gal = 66,500 gal	

Calculate the percent of water used for backwashing.

$$\begin{aligned}\text{Backwash, \%} &= \frac{(\text{Backwash Water, gal})(100\%)}{\text{Water Filtered, gal}}\\ &= \frac{(66{,}500)(100\%)}{13{,}000{,}000\text{ gal}}\\ &= 0.5\%\end{aligned}$$

A.136 Disinfection

EXAMPLE 33

Calculate the chlorine dose in mg/*L* when a chlorinator is set to feed 18 pounds of chlorine in 24 hours. The flow is 570,000 gallons per day.

Known	Unknown
Chlorinator Setting, lbs/24 hrs = 18 lbs Cl/24 hr	Chlorine Dose, mg/*L*
Flow, MGD = 0.57 MGD	

Calculate the chlorine dose in milligrams per liter.

$$\begin{aligned}\text{Chlorine Dose, mg}/L &= \frac{\text{Chlorine Feed, lbs/day}}{(\text{Flow, MGD})(8.34\text{ lbs/gal})}\\ &= \frac{18\text{ lbs/day}}{(0.57\text{ MGD})(8.34\text{ lbs/gal})}\\ &= 3.8\text{ mg}/L\end{aligned}$$

EXAMPLE 34

Estimate the chlorine demand for a water in milligrams per liter if the chlorine dose is 2.9 mg/*L* and the chlorine residual is 0.6 mg/*L*.

Known	Unknown
Chlorine Dose, mg/*L* = 2.9 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L* = 0.6 mg/*L*	

Estimate the chlorine demand of the water in milligrams per liter.

$$\begin{aligned}\text{Chlorine Demand, mg}/L &= \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L\\ &= 2.9\text{ mg}/L - 0.6\text{ mg}/L\\ &= 2.3\text{ mg}/L\end{aligned}$$

EXAMPLE 35

Calculate the pounds of chlorine used to disinfect water if 150 gallons of hypochlorite as a 2.5 percent chlorine solution was used.

Known	Unknown
Hypochlorite, gal = 150 gal	Chlorine, lbs
Hypochlorite, % = 2.5%	

Calculate the pounds of chlorine used.

$$\begin{aligned}\text{Chlorine, lbs} &= \frac{(\text{Hypochlorite, gal})(8.34\text{ lbs/gal})(\text{Hypochlorite, \%})}{100\%}\\ &= \frac{(150\text{ gal})(8.34\text{ lbs/gal})(2.5\%)}{100\%}\\ &= 31.3\text{ lbs chlorine}\end{aligned}$$

EXAMPLE 36

Estimate the flow pumped by a hypochlorinator in gallons per day if the hypochlorite solution is in a container with a diameter of 30 inches (2.5 feet) and the hypochlorite level drops 14 inches during a nine-hour period. The hypochlorinator operated continuously during the nine-hour period.

Known	Unknown
Diameter, ft = 2.5 ft	Hypochlorinator, Flow, GPD
Drop, in = 14 in	
Time, hr = 9 hr	

Calculate the hypochlorinator flow in gallons per day.

$$\text{Flow, GPD} = \frac{(\text{Container Area, sq ft})(\text{Drop, in})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}{(\text{Time, hr})(12\ \text{in/ft})}$$

$$= \frac{(0.785)(2.5\ \text{ft})^2\,(14\ \text{in})(7.48\ \text{gal/cu ft})(24\ \text{hr/day})}{(9\ \text{hr})(12\ \text{in/ft})}$$

$$= 114\ \text{GPD}$$

EXAMPLE 37

Estimate the desired strength (as a percent chlorine) of a hypochlorite solution which is pumped by a hypochlorinator that delivers 115 gallons per day. The water being treated requires a chlorine dose of twelve pounds of chlorine per day.

Known		Unknown
Hypochlorinator Flow, GPD	=115 GPD	Hypochlorite Strength, %
Chlorine Required, lbs/day	=12 lbs/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, lbs/day})(100\%)}{(\text{Hypochlorinator Flow, gal/day})(8.34\ \text{lbs/gal})}$$

$$= \frac{(12\ \text{lbs/day})(100\%)}{(115\ \text{GPD})(8.34\ \text{lbs/gal})}$$

$$= 1.25\%$$

EXAMPLE 38

How many gallons of water must be added to fifteen gallons of five percent hypochlorite solution to produce a 1.25 percent hypochlorite solution?

Known		Unknown
Hypochlorite, gal	=15 gal	Water Added, gal
Desired Hypo, %	=1.25%	
Actual Hypo, %	=5%	

Calculate the gallons of water that must be added to produce a 1.25 percent hypochlorite solution.

$$\text{Water Added, gal (to hypochlorite solution)} = \frac{(\text{Hypo, gal})(\text{Hypo, \%}) - (\text{Hypo, gal})(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(15\ \text{gal})(5\%) - (15\ \text{gal})(1.25\%)}{1.25\%}$$

$$= \frac{75 - 18.75}{1.25}$$

$$= 45\ \text{gallons}$$

A.137 Corrosion Control

EXAMPLE 39

Calculate the Driving Force Index (D.F.I.) of a water at 12°C having a TDS of 100 mg/*L*, a calcium hardness of 60 mg/*L* as $CaCO_3$ and a carbonate ($CO_3{}^{2-}$) level of 2 mg/*L* as $CaCO_3$. The K'_{sp} value for calcium carbonate ($CaCO_3$) is 6.683×10^{-9}.

Known		Unknown
Water Temp, °C	=12°C	D.F.I.
TDS, mg/*L*	=200 mg/*L*	
Ca Hardness, mg/*L*	=60 mg/*L* as $CaCO_3$	
$CO_3{}^{2-}$, mg/*L*	=2 mg/*L* as $CaCO_3$	
K'_{sp} for $CaCO_3$	$=6.683 \times 10^{-9}$	

Calculate the Driving Force Index (D.F.I.).

$$\text{D.F.I.} = \frac{[Ca^{2+}][CO_3{}^{2-}]}{K'_{sp} \times 10^{10}}$$

$$= \frac{[60\ \text{mg}/L][2\ \text{mg}/L]}{(6.683 \times 10^{-9})(10^{10})}$$

$$= 1.80$$

When the D.F.I. is greater than one, the water is supersaturated with calcium carbonate.

EXAMPLE 40

Find the pH_s of a water at 10°C having a TDS of 100 mg/*L*, alkalinity of 40 mg/*L* and a calcium hardness of 60 mg/*L*.

Known		Unknown
Water Temp, °C	= 10°C	pH_S
TDS, mg/*L*	= 100 mg/*L*	
Alky, mg/*L*	= 40 mg/*L*	
Ca Hardness, mg/*L*	= 60 mg/*L* as $CaCO_3$	

1. Find the formula values from the tables in Chapter 8, "Corrosion Control."

   From Table 8.3 for a water temperature of 10°C,

   A = 2.20

   From Table 8.4 for a TDS of 100 mg/*L*,

   B = 9.75

   From Table 8.5 for Alky of 40 mg/*L* and Ca of 60 mg/*L*,

   $\log(Ca^{2+}) = 1.48$,

   $\log(\text{Alky}) = 1.78$

2. Calculate pH_S.

$$pH_S = A + B - \log(Ca^{2+}) - \log(\text{Alky})$$

$$= 2.20 + 9.75 - 1.48 - 1.78$$

$$= 8.69$$

EXAMPLE 41

Calculate the Langelier Index for a water with a calculated pH_S value of 8.69 and an actual pH of 8.5.

Known		Unknown
pH_S	= 8.69	Langelier Index
pH	= 8.5	

Calculate the Langelier Index.

$$\text{Langelier Index} = pH - pH_S$$

$$= 8.5 - 8.69$$

$$= -0.19$$

Since the Langelier Index is negative, the water is corrosive.

A.138 Plant Operation

EXAMPLE 42

Estimate the average use of chlorine in pounds per day based on actual use of chlorine for one week as shown below.

Day	Sun	Mon	Tues	Wed	Thurs	Fri	Sat
Chlorine Use, lbs	23	37	35	31	32	36	24

Known	Unknown
Chlorine Use, lbs/day	Average Chlorine Use, lbs/day

Estimate the average chlorine use in pounds of chlorine per day.

$$\text{Average Chlorine Use, lbs/day} = \frac{\text{Sum of Chlorine Used Each Day, lbs}}{\text{Total Time, days}}$$

$$= \frac{23\text{ lbs}+37\text{ lbs}+35\text{ lbs}+31\text{ lbs}+32\text{ lbs}+36\text{ lbs}+24\text{ lbs}}{7\text{ days}}$$

$$= 31.1\text{ lbs/day}$$

EXAMPLE 43

A water treatment plant has five 150-pound chlorine cylinders in storage. The plant uses an average of 28 pounds of chlorine per day. How many days' supply of chlorine is in storage?

Known		Unknown
Chlorine Cylinders	= 5 cylinders	Supply of Chlorine, days
Cylinder Wt., lbs/cyl	= 150 lbs/cyl	
Ave. Use, lbs/day	= 28 lbs/day	

Calculate the available supply of chlorine in storage in days.

$$\text{Supply of Chlorine, days} = \frac{(\text{Cylinder Wt, lbs/cyl})(\text{No. of cylinders})}{\text{Ave. Use, lbs/day}}$$

$$= \frac{(150\text{ lbs/cyl})(5\text{ cylinders})}{28\text{ lbs/day}}$$

$$= 27\text{ days}$$

A.139 Laboratory Procedures

EXAMPLE 44

Convert the temperature of water from 65° Fahrenheit to degrees Celsius.

Known	Unknown
Temp, °F = 65°F	Temp, °C

Change 65°F to degrees Celsius.

$$\text{Temperature, °C} = \frac{5}{9}(\text{°F} - 32\text{°F})$$

$$= \frac{5}{9}(65\text{°F} - 32\text{°F})$$

$$= 18.3\text{°C}$$

EXAMPLE 45

Convert a water temperature of 12° Celsius to degrees Fahrenheit.

Known	Unknown
Temp, °C = 12°C	Temp, °F

Change 12°C to degrees Fahrenheit.

$$\text{Temp, °F} = \frac{9}{5}(\text{°C}) + 32\text{°F}$$

$$= \frac{9}{5}(12\text{°C}) + 32\text{°F}$$

$$= 53.6\text{°F}$$

EXAMPLE 46

In the determination of a chlorine residual by the drop-diluation method, three drops of sample produced a chlorine residual of 0.2 mg/*L* in 10 m*L* of distilled water. Assume 0.05 m*L* per drop.

Known		Unknown
Chlorine Residual, mg/*L*	= 0.2 mg/*L*	Actual Chlorine Residual, mg/*L*
Sample Volume, drops	= 3 drops	
Distilled Water, m*L*	= 10 m*L*	

Calculate the actual chlorine residual in milligrams per liter.

$$\text{Actual Chlorine Residual, mg/}L = \frac{(\text{Chlorine Residual, mg/}L)(\text{Distilled Water, m}L)}{(\text{Sample Volume, drops})(0.05\text{ m}L\text{/drop})}$$

$$= \frac{(0.2\text{ mg/}L)(10\text{ m}L)}{(3\text{ drops})(0.05\text{ m}L\text{/drop})}$$

$$= 13\text{ mg/}L$$

EXAMPLE 47

Results from the MPN tests during one week were as follows:

Day	S	M	T	W	T	F	S
MPN/100 m*L*	2	4	6	7	9	5	2

Estimate the (1) mean, (2) median, and (3) geometric mean of the data in MPN/100 m*L*.

1. Calculate the mean.

$$\text{Mean, MPN/100 m}L = \frac{\text{Sum of All MPNs}}{\text{Number of MPNs}}$$

$$= \frac{2+4+6+7+9+5+2}{7}$$

$$= \frac{35}{7}$$

$$= 5\text{ MPN/100 m}L$$

2. Determine the median. Rearrange the data in ascending (increasing) order and select the middle value (three will be smaller and three will be larger in this example).

Order	1	2	3	4	5	6	7
MPN/100 m*L*	2	2	4	5 ↑	6	7	9

$$\text{Median, MPN/100 m}L = \text{Middle value of a group of data}$$

$$= 5\text{ MPN/100 m}L$$

3. Calculate the geometric mean for the given data.

$$\begin{aligned}\text{Geometric Mean, MPN/100 m}L &= [(X_1)(X_2)(X_3)(X_4)(X_5)(X_6)(X_7)]^{1/7}\\ &= [(2)(4)(6)(7)(9)(5)(2)]^{1/7}\\ &= [30{,}240]^{0.143}\\ &= 4.4\ \text{MPN/100 m}L\end{aligned}$$

A.14 BASIC CONVERSION FACTORS (METRIC SYSTEM)

LENGTH		
100 cm	= 1 m	100 cm/m
3.281 ft	= 1 m	3.281 ft/m
AREA		
2.4711 ac	= 1 ha*	2.4711 ac/ha
10,000 sq m	= 1 ha	10,000 sq m/ha
VOLUME		
1000 m*L*	= 1 liter	1000 m*L*/*L*
1000 *L*	= 1 cu m	1000 *L*/cu m
3.785 *L*	= 1 gal	3.785 *L*/gal
WEIGHT		
1000 mg	= 1 gm	1000 mg/gm
1000 gm	= 1 kg	1000 gm/kg
DENSITY		
1 kg	= 1 liter	1 kg/*L*
PRESSURE		
10.015 m	= 1 kg/sq cm	10.015 m/kg/sq cm
1 Pascal	= 1 N/sq m	1 Pa/N/sq m
1 psi	= 6895 Pa	1 psi/6895 Pa
FLOW		
3785 cu m/day	= 1 MGD	3785 cu m/day/MGD
3.785 M*L*/day	= 1 MGD	3.785 M*L*/day/MGD

*hectare

A.15 TYPICAL WATER TREATMENT PLANT PROBLEMS (METRIC SYSTEM)

A.150 Flows

EXAMPLE 1

Convert a flow of 500 gallons per minute to liters per second and cubic meters per day.

Known	Unknown
Flow, GPM = 500 GPM	1. Flow, liters/sec 2. Flow, cu m/day

1. Convert the flow from 500 GPM to liters per second.

$$\begin{aligned}\text{Flow, liters/sec} &= \frac{(\text{Flow, gal/min})(3.785\ \text{liters/gal})}{60\ \text{sec/min}}\\ &= \frac{(500\ \text{gal/min})(3.785\ \text{liters/gal})}{60\ \text{sec/min}}\\ &= 31.5\ \text{liters/sec}\end{aligned}$$

2. Convert the flow from 500 GPM to cubic meters per day.

$$\begin{aligned}\text{Flow, cu m/day} &= \frac{(\text{Flow, gal/min})(3.785\ L/\text{gal})(60\ \text{min/hr})(24\ \text{hr/day})}{1000\ L/\text{cu m}}\\ &= \frac{(500\ \text{gal/min})(3.785\ L/\text{gal})(60\ \text{min/hr})(24\ \text{hr/day})}{1000\ L\ \text{cu/m}}\\ &= 2725\ \text{cu m/day}\end{aligned}$$

A.151 Chemical Doses

EXAMPLE 2

Determine the chlorinator setting in kilograms per 24 hours if 4000 cubic meters of water per day are to be treated with a desired chlorine dose of 2.5 mg/*L*.

Known		Unknown
Flow, cu m/day	= 4000 cu m/day	Chlorinator Setting, kg/24 hours
Chlorine Dose, mg/*L*	= 2.5 mg/*L*	

Determine the chlorinator setting in kilograms per 24 hours.

$$\begin{aligned}\text{Chlorinator Setting, kg/day} &= \frac{(\text{Flow, cu m/day})(\text{Dose, mg}/L)(1{,}000\ L/\text{cu m})}{(1000\ \text{mg/gm})(1000\ \text{gm/kg})}\\ &= \frac{(4000\ \text{cu m/day})(2.5\ \text{mg}/L)(1{,}000\ L/\text{cu m})}{(1000\ \text{mg/gm})(1000\ \text{gm/kg})}\\ &= 10\ \text{kg/day}\end{aligned}$$

EXAMPLE 3

The optimum liquid alum dose from the jar tests is 12 mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the plant flow is 15 megaliters per day (or million liters per day). The liquid alum delivered to the plant contains 642.3 milligrams of alum per milliliter of solution.

Known		Unknown
Alum Dose, mg/*L*	= 12 mg/*L*	Chemical Feeder Setting, m*L*/min
Flow, M*L*/day	= 15 M*L*/day	
Liquid Alum, mg/m*L*	= 642.3 mg/m*L*	

Calculate the liquid alum chemical feeder setting in milliliters per minute.

$$\begin{aligned}\text{Chemical Feeder Setting, m}L\text{/min} &= \frac{(\text{Flow, M}L/\text{day})(\text{Alum Dose, mg}/L)(1{,}000{,}000)}{(\text{Liquid Alum, mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}\\ &= \frac{(15\ \text{M}L/\text{day})(12\ \text{mg}/L)(1{,}000{,}000)}{(642.3\ \text{mg/m}L)(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}\\ &= 195\ \text{m}L/\text{min}\end{aligned}$$

EXAMPLE 4

The optimum liquid alum dose from jar tests is 8 mg/*L*. Determine the setting on the liquid alum chemical feeder in milliliters per minute when the flow is 12 megaliters per day. The liquid alum delivered to the plant contains 5.36 pounds of alum per gallon of liquid solution.

Known		Unknown
Alum Dose, mg/*L*	= 8 mg/*L*	Chemical Feeder Setting, m*L*/min
Flow, M*L*/day	= 12 M*L*/day	
Liquid Alum, lb/gal	= 5.36 lbs/gal	

Calculate the liquid alum chemical feeder setting in milliliters per minute.

$$\text{Chemical Feeder Setting, m}L\text{/min} = \frac{(\text{Flow, M}L\text{/day})(\text{Alum Dose, mg/}L)(3.785\ L\text{/gal})(1000\ \text{m}L/L)(1{,}000{,}000)}{(\text{Liquid Alum, lbs/gal})(454\ \text{gm/lb})(1000\ \text{mg/gm})(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}$$

$$= \frac{(12\ \text{M}L\text{/day})(8\ \text{mg/}L)(3.785\ L\text{/gal})(1000\ \text{m}L/L)(1{,}000{,}000)}{(5.36\ \text{lbs/gal})(454\ \text{gm/lb})(1000\ \text{mg/gm})(24\ \text{hr/day})(60\ \text{min/hr})(1\ \text{Million})}$$

$$= 104\ \text{m}L\text{/min}$$

EXAMPLE 5

Determine the actual chemical dose or chemical feed in kilograms per day from a dry chemical feeder. A bucket placed under the chemical feeder weighed 150 grams empty and 1800 grams after 12 minutes.

Known		Unknown
Empty Bucket, gm	= 150 gm	Chemical Feed, kg/day
Full Bucket, gm	= 1800 gm	
Time to fill, min	= 12 min	

$$\text{Chemical Feed, kg/day} = \frac{\text{Chemical Applied, kg}}{\text{Length of Application, days}}$$

$$= \frac{(1800\ \text{gm} - 150\ \text{gm})(60\ \text{min/hr})(24\ \text{hr/day})}{(1000\ \text{gm/kg})(12\ \text{min})}$$

$$= 198\ \text{kg/day}$$

EXAMPLE 6

Determine the chemical feed in kilograms of polymer per day from a chemical feed pump. The polymer solution is 1.5 percent or 15,000 mg polymer per liter. Assume a specific gravity of the polymer solution of 1.0. During a test run the chemical feed pump delivered 800 m*L* of polymer solution during five minutes.

Known		Unknown
Polymer Solution, %	= 1.5%	Polymer Feed, kg/day
Polymer Conc, mg/*L*	= 15,000 mg/*L*	
Polymer Sp Gr	= 1.0	
Vol Pumped, m*L*	= 800 m*L*	
Time Pumped, min	= 5 min	

Calculate the polymer fed by the chemical feed pump in kilograms of polymer per day.

$$\text{Polymer Feed, kg/day} = \frac{(\text{Poly Conc, mg/}L)(\text{Vol Pumped, m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(\text{Time Pumped, min})(1000\ \text{m}L/L)(1000\ \text{mg/gm})(1000\ \text{gm/kg})}$$

$$= \frac{(15{,}000\ \text{mg/}L)(800\ \text{m}L)(60\ \text{min/hr})(24\ \text{hr/day})}{(5\ \text{min})(1000\ \text{m}L/L)(1000\ \text{mg/gm})(1000\ \text{gm/kg})}$$

$$= 3.5\ \text{kg/day}$$

EXAMPLE 7

A small chemical feed pump lowered the chemical solution in an 80-centimeter diameter tank 35 centimeters during an eight-hour period. Estimate the flow delivered by the pump in liters per minute.

Known		Unknown
Tank Diameter, cm	= 80 cm	Flow, liters/min
Chemical Drop, cm	= 35 cm	
Time, hr	= 8 hr	

Calculate the flow in liters per minute.

$$\text{Flow, liters/min} = \frac{(\text{Area, sq m})(\text{Drop, m})(1000\ \text{liters/cu m})}{(\text{Time, hr})(60\ \text{min/hr})}$$

$$= \frac{(0.785)(0.8\ \text{m})^2(0.35\ \text{m})(1000\ \text{liters/cu m})}{(8\ \text{hr})(60\ \text{min/hr})}$$

$$= 0.37\ \text{liters/min}$$

EXAMPLE 8

Determine the settings in percent stroke on a chemical feed pump for various doses of a chemical in milligrams per liter. (The chemical could be chlorine, polymer, potassium permanganate or any other chemical solution fed by a pump.) The pump delivering water to be treated pumps at a flow rate of 25 liters per second. The solution strength of the chemical being pumped is five percent. The chemical feed pump has a maximum capacity of 250 milliliters per minute at a setting of 100 percent capacity.

Known		Unknown
Pump Flow, *L*/sec	= 25 *L*/sec	Settings, % stroke for various doses in mg/*L*
Solution Strength, %	= 5%	
Feed Pump, m*L*/min (100% stroke)	= 250 m*L*/min	

1. Change the chemical solution strength from a percent to milligrams of chemical per liter of solution. A 5 percent solution means we have 5 milligrams of chemical in a solution of water and chemical weighing 100 milligrams.

$$\text{Chemical Solution, mg/}L = \frac{5\ \text{mg chemical}}{100\ \text{mg of chemical and water}}$$

$$= \frac{(5\ \text{mg})(1{,}000{,}000\ \text{mg/}L)}{100\ \text{mg}}$$

$$= 50{,}000\ \text{mg/}L$$

2. Calculate the chemical feed in kilograms per day for a chemical dose of 0.5 milligrams per liter. We are going to assume various chemical doses of 0.5, 1.0, 1.5, 2.0, 2.5 mg/*L* and upward so that if we know the desired chemical dose, we can easily determine the setting (percent stroke) on the chemical feed pump.

$$\text{Chemical Feed, kg/day} = \frac{(\text{Flow, }L\text{/sec})(\text{Dose, mg/}L)(60\ \text{sec/min})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000\ \text{mg/kg}}$$

$$= \frac{(25\ L\text{/sec})(0.5\ \text{mg/}L)(60\ \text{sec/min})(60\ \text{min/hr})(24\ \text{hr/day})}{1{,}000{,}000\ \text{mg/kg}}$$

$$= 1.1\ \text{kg/day}$$

3. Determine the desired flow from the chemical feed pump in milliliters per minute.

$$\text{Feed Pump, m}L\text{/min} = \frac{\text{Chemical Feed, kg/day}}{\text{Chemical Solution, mg/}L}$$

$$= \frac{(1.1\ \text{kg/day})(1000\ \text{m}L/L)(1{,}000{,}000\ \text{mg/kg})}{(50{,}000\ \text{mg/}L)(24\ \text{hr/day})(60\ \text{min/hr})}$$

$$= 15.3\ \text{m}L\text{/min}$$

4. Determine the setting in the chemical feed pump as a percent. In this case we want to know the setting as a percent of the pump stroke.

$$\text{Setting, \%} = \frac{(\text{Desired Feed Pump, m}L\text{/min})(100\%)}{\text{Maximum Feed Pump, m}L\text{/min}}$$

$$= \frac{(15.3\ \text{m}L\text{/min})(100\%)}{250\ \text{m}L\text{/min}}$$

$$= 6.1\%$$

5. If we changed the chemical dose in Step 2 from 0.5 mg/*L* to 1.0 mg/*L* and other higher doses and repeated the remainder of the steps, we could calculate the data in Table A.2.

TABLE A.2 SETTINGS FOR CHEMICAL FEED PUMP

PUMP FLOW, *L*/sec = 25 *L*/sec

SOLUTION STRENGTH, % = 5.0%

Chemical Dose, mg/*L*	Chemical Feed, kg/day	Feed Pump, m*L*/min	Pump Setting, % stroke
0.5	1.1	15.3	6.1
1.0	2.2	30.6	12.2
2.0	4.3	59.7	23.9
4.0	8.6	119.4	47.8
6.0	13.0	180.6	72.2
8.0	17.3	240.3	96.0

6. The data in Table A.2 could be plotted to produce a chart similar to Figure A.3 (page 570). For any desired chemical dose in milligrams per liter, the chart could be used to determine the necessary chemical feed pump setting.

A.152 Reservoir Management and Intake Structures

EXAMPLE 9

The volume of a reservoir is estimated to be 581,000 cubic feet. Estimate the volume in cubic meters.

Known		Unknown
Reservoir Vol, cu ft	= 581,000 cu ft	Reservoir Vol, cu m

Estimate the reservoir volume in cubic meters.

$$\text{Reservoir Vol, cu m} = \frac{\text{Reservoir Vol, cu ft}}{(3.281\ \text{ft/m})^3}$$

$$= \frac{581{,}000\ \text{cu ft}}{(3.281\ \text{ft/m})^3}$$

$$= 16{,}450\ \text{cu m}$$

EXAMPLE 10

A reservoir has a surface area of 0.75 hectare and an average depth of seven meters. Estimate the volume of the reservoir in cubic meters.

Known		Unknown
Surface Area, ha	= 0.75 ha	Reservoir Vol, cu m
Depth, m	= 7 m	

Estimate the reservoir volume in cubic meters.

$$\text{Reservoir Vol, cu m} = (\text{Surface Area, ha})(\text{Depth, m})(10{,}000\ \text{sq m/ha})$$

$$= (0.75\ \text{ha})(7\ \text{m})(10{,}000\ \text{sq m/ha})$$

$$= 52{,}500\ \text{cu m}$$

EXAMPLE 11

A reservoir has a surface area of 0.48 hectare and the desired dose of copper sulfate is three kilograms per hectare. How many kilograms of copper sulfate will be needed?

Known		Unknown
Surface Area, ha	= 0.48 ha	Copper Sulfate, kg
Dose, kg/ha	= 3 kg/ha	

Calculate the kilograms of copper sulfate needed.

$$\text{Copper Sulfate, kg} = (\text{Surface Area, ha})(\text{Dose, kg/ha})$$

$$= (0.48\ \text{ha})(3\ \text{kg/ha})$$

$$= 1.44\ \text{kg}$$

EXAMPLE 12

The volume of a reservoir is estimated to be 16,000 cubic meters. The desired chemical dose is 0.5 mg/*L*. Estimate the chemical dose in kilograms.

Known		Unknown
Reservoir Vol, cu m	= 16,000 cu m	Chemical Dose, kg
Chemical Dose, mg/*L*	= 0.5 mg/*L*	

Estimate the chemical dose in kilograms.

$$\text{Chemical Dose, kg} = \frac{(\text{Volume, cu m})(\text{Dose, mg/}L)(1000\ L\text{/cu m})}{(1000\ \text{mg/gm})(1000\ \text{gm/kg})}$$

$$= \frac{(16{,}000\ \text{cu m})(0.5\ \text{mg/}L)(1000\ L\text{/cu m})}{(1000\ \text{mg/gm})(1000\ \text{gm/kg})}$$

$$= 8\ \text{kg}$$

EXAMPLE 13

The volume of a reservoir is estimated to be 16,000 cubic meters. The desired dose of copper is 0.5 mg/*L* and the copper content of the copper sulfate to be used is 25 percent. How many kilograms of copper sulfate will be needed?

Known		Unknown
Reservoir Volume, cu m	= 16,000 cu m	Copper Sulfate, kg
Copper Dose, mg/*L*	= 0.5 mg/*L*	
Copper, %	= 25%	

Calculate the kilograms of copper sulfate that will be needed.

$$\text{Copper Sulfate, kg} = \frac{(\text{Volume, cu m})(\text{Dose, mg/}L)(1000\ L\text{/cu m})(100\%)}{(1000\ \text{mg/gm})(1000\ \text{gm/kg})(\text{Copper, \%})}$$

$$= \frac{(16{,}000\ \text{cu m})(0.5\ \text{mg/}L)(1000\ L\text{/cu m})(100\%)}{(1000\ \text{mg/gm})(1000\ \text{gm/kg})(25\%)}$$

$$= 32\ \text{kg}$$

A.153 Coagulation and Flocculation

EXAMPLE 14

A polymer feed pump delivers 600 liters per day containing a five percent polymer solution with a specific gravity of 1.02. Estimate the polymer delivered in kilograms per day.

Known		Unknown
Flow, liters/day	= 600 liters/day	Polymer, kg/day
Polymer, %	= 5%	
Polymer, mg/*L*	= 50,000 mg/*L*	
Sp Gr	= 1.02	

Estimate the polymer delivered in kilograms per day.

Solution 1

$$\text{Polymer, kg/day} = \frac{(\text{Polymer Flow, } L\text{/day})(1 \text{ kg/}L)(\text{Polymer, \%})(\text{Sp Gr})}{(100\%)}$$

$$= \frac{(600 \ L\text{/day})(1 \text{ kg/}L)(5\%)(1.02)}{100\%}$$

$$= 30.6 \text{ kg/day}$$

Solution 2

$$\text{Polymer, kg/day} = \frac{(\text{Polymer Flow, } L\text{/day})(\text{Polymer, mg/}L)(\text{Sp Gr})}{(1000 \text{ mg/gm})(1000 \text{ gm/kg})}$$

$$= \frac{(600 \ L\text{/day})(50{,}000 \text{ mg/}L)(1.02)}{(1000 \text{ mg/gm})(1000 \text{ gm/kg})}$$

$$= 30.6 \text{ kg/day}$$

EXAMPLE 15

Estimate the actual alum dose in milligrams per liter if a plant treats a raw water with a flow of 7.0 M*L*/day. The alum feed rate is 60 kg per day.

Known		Unknown
Flow, M*L*/day	= 7.0 M*L*/day	Alum Dose, mg/*L*
Alum Feed, kg/day	= 60 kg/day	

Calculate the alum dose in milligrams per liter.

Basic Equation

$$\text{Alum Feed, kg/day} = (\text{Flow, M}L\text{/day})(\text{Alum Dose, mg/}L)(1 \text{ kg/M mg})$$

OR

$$\text{Alum Dose, mg/}L = \frac{\text{Alum Feed, kg/day}}{(\text{Flow, M}L\text{/day})(1 \text{ kg/M mg})}$$

$$= \frac{60 \text{ kg/day}}{(7.0 \text{ M}L\text{/day})(1 \text{ kg/M mg})}$$

$$= 8.6 \text{ mg/}L$$

EXAMPLE 16

Determine the strength of a polymer solution as a percent if 80 grams of dry polymer are mixed with 16 liters of water.

Known		Unknown
Dry Polymer, gm	= 80 gm	Polymer Solution, %
Volume Water, *L*	= 16 *L*	

1. Convert the sixteen liters of water to grams.

$$\text{Water, gm} = (\text{Volume Water, } L)(1000 \text{ gm/}L)$$

$$= (16 \ L)(1000 \text{ gm/}L)$$

$$= 16{,}000 \text{ gm}$$

2. Calculate the polymer solution as a percent.

$$\text{Polymer, \%} = \frac{(\text{Dry Polymer, gm})(100\%)}{(\text{Dry Polymer, gm} + \text{Water, gm})}$$

$$= \frac{(80 \text{ gm})(100\%)}{(80 \text{ gm} + 16{,}000 \text{ gm})}$$

$$= 0.50\%$$

EXAMPLE 17

Liquid polymer is supplied to a water treatment plant as a ten percent solution. How many liters of liquid polymer should be mixed in a tank with water to produce 750 liters at 0.8 percent polymer solution?

Known		Unknown
Liquid Polymer, %	= 10%	Volume of Liquid Polymer, *L*
Polymer Solution,%	= 0.8%	
Volume of Polymer Solution, *L*	= 750 *L*	

Calculate the volume of liquid polymer in liters.

$$\text{Liquid Polymer, } L = \frac{(\text{Polymer Solution, \%})(\text{Volume of Solution, } L)}{\text{Liquid Polymer, \%}}$$

$$= \frac{(0.8\%)(750 \ L)}{10\%}$$

$$= 60 \text{ liters}$$

A.154 Sedimentation

EXAMPLE 18

Estimate the detention time in hours for a 10-meter diameter circular clarifier when the flow is 2000 cubic meters per day. The clarifier is three meters deep.

Known		Unknown
Diameter, m	= 10 m	Detention, Time hr
Depth, m	= 3 m	
Flow, cu m/day	= 2000 cu m/day	

1. Calculate the clarifier volume in cubic meters.

$$\text{Volume, cu m} = (\text{Area, sq m})(\text{Depth, m})$$

$$= (0.785)(10 \text{ m})^2(3 \text{ m})$$

$$= 235.5 \text{ cu m}$$

2. Estimate the detention time of the clarifier in hours.

$$\text{Detention Time, hr} = \frac{(\text{Volume, cu m})(24 \text{ hr/day})}{\text{Flow, cu m/day}}$$

$$= \frac{(235.5 \text{ cu m})(24 \text{ hr/day})}{2000 \text{ cu m/day}}$$

$$= 2.8 \text{ hr}$$

EXAMPLE 19

Estimate the overflow rate in millimeters per second for a rectangular sedimentation basin 6-meters wide and 12-meters long when the flow is 2000 cubic meters per day.

Known		Unknown
Width, m	= 6 m	Overflow Rate, mm/sec
Length, m	= 12 m	
Flow, cu m/day	= 2000 cu m/day	

Determine the overflow rate for the basin in millimeters per second.

$$\text{Overflow Rate,} = \frac{(\text{Flow, cu m/day})(1000\text{ mm/m})}{(\text{Area, sq m})(24\text{ hr/day})(60\text{ min/hr})(60\text{ min/sec})}$$

$$= \frac{(2000\text{ cu m/day})(1000\text{ mm/m})}{(6\text{ m})(12\text{ m})(24\text{ hr/day})(60\text{ min/hr})(60\text{ sec/min})}$$

$$= 0.32\text{ mm/sec}$$

EXAMPLE 20

Estimate the flow velocity in meters per minute through a rectangular sedimentation basin six-meters wide and 2.5-meters deep when the flow is 20 liters per second.

Known		Unknown
Width, m	= 6 m	Flow Velocity, m/min
Depth, m	= 2.5 m	
Flow, *L*/sec	= 20 *L*/sec	

Estimate the flow velocity in meters per minute.

$$\text{Flow Velocity, m/min} = \frac{(\text{Flow, }L\text{/sec})(60\text{ sec/min})}{(\text{Cross-Sectional Area, sq m})}$$

$$= \frac{(20\ L\text{/sec})(60\text{ sec/min})}{(6\text{ m})(2.5\text{ m})(1000\ L\text{/cu m})}$$

$$= 0.08\text{ m/min}$$

EXAMPLE 21

Estimate the weir loading in cubic meters per day per meter of weir length for a ten-meter diameter circular clarifier treating a flow of 20 liters per second. The weir is located on the water edge of the clarifier.

KNOWN		UNKNOWN
Weir Diameter, m	= 10 m	Weir Loading, cu m/day/m
Flow, *L*/sec	= 20 *L*/sec	

1. Calculate the weir length in meters.

$$\text{Weir Length, m} = \pi\ (\text{Diameter, m})$$

$$= 3.14\ (10\text{ m})$$

$$= 31.4\text{ m}$$

2. Estimate the weir loading in cubic meters per day per meter.

$$\text{Weir Loading, cu m/day/m} = \frac{\text{Flow, cu m/day}}{\text{Weir Length, m}}$$

$$= \frac{(20\ L\text{/sec})(60\text{ sec/min})(60\text{ min/hr})(24\text{ hr/day})}{(31.4\text{ m})(1000\ L\text{/cu m})}$$

$$= 55\text{ cu m/day/m}$$

A.155 Filtration

EXAMPLE 22

A 7.5-meter wide by nine-meter long rapid sand filter treats a flow of 125 liters per second. Calculate the filtration rate in liters per second per square meter and also in millimeters per second.

Known		Unknown
Width, m	= 7.5 m	1. Filtration Rate, *L*/sec/sq m
Length, m	= 9 m	2. Filtration Rate, mm/sec
Flow, *L*/sec	= 125 *L*/sec	

1. Calculate the filtration rate in liters per second per square meter of filter surface area.

$$\text{Filtration Rate, }L\text{/sec/sq m} = \frac{\text{Flow, liters/sec}}{\text{Surface Area, sq m}}$$

$$= \frac{125\ L\text{/sec}}{(7.5\text{ m})(9\text{ m})}$$

$$= 1.85\ L\text{/sec/sq m}$$

2. Calculate the filtration rate in millimeters per second.

$$\text{Filtration Rate, mm/sec} = \frac{(\text{Flow, }L\text{/sec})(1000\text{ mm/m})}{(\text{Surface Area, sq m})(1000\ L\text{/cu m})}$$

$$= \frac{(125\ L\text{/sec})(1000\text{ mm/m})}{(7.5\text{ m})(9\text{ m})(1000\ L\text{/cu m})}$$

$$= 1.85\text{ mm/sec}$$

EXAMPLE 23

With the inflow water to a rapid sand filter shut off, the water is observed to drop 50 centimeters in nine minutes. What is the velocity of the water dropping in meters per minute?

Known		Unknown
Water Drop, cm	= 50 cm	Velocity of Drop, m/min
Time of Drop, min	= 9 min	

Calculate the velocity of the water drop in meters per minute.

$$\text{Velocity, m/min} = \frac{\text{Water Drop, m}}{\text{Time of Drop, min}}$$

$$= \frac{(50\text{ cm})}{(100\text{ cm/m})(9\text{ min})}$$

$$= 0.056\text{ m/min}$$

EXAMPLE 24

Estimate the flow through a rapid sand filter in cubic meters per minute when the velocity of the water dropping is 0.05 meters per minute and the filter is 7.5-meters wide and 9-meters long.

Known		Unknown
Velocity of Drop, m/min	= 0.05 m/min	Flow, cu m/min
Width, m	= 7.5 m	
Length, m	= 9 m	

Estimate the flow through the filter in cubic meters per minute.

$$\text{Flow, cu m/min} = (\text{Area, sq ft})(\text{Velocity, m/min})$$

$$= (7.5\text{ m})(9\text{ m})(0.05\text{ m/min})$$

$$= 3.38\text{ cu m/min}$$

EXAMPLE 25

Calculate the flow through a rapid sand filter in liters per second when the flow is 3.5 cubic meters per minute.

	Known	Unknown
Flow, cu m/min	=3.5 cu m/min	Flow, *L*/sec

Calculate the flow through the filter in liters per second.

$$\text{Flow, } L\text{/sec} = \frac{(\text{Flow, cu m/min})(1000\ L\text{/cu m})}{60 \text{ sec/min}}$$

$$= \frac{(3.5 \text{ cu m/min})(1000\ L\text{/cu m})}{60 \text{ sec/min}}$$

$$= 58.3\ L\text{/sec}$$

EXAMPLE 26

Calculate the flow through a rapid sand filter in liters per second when 6000 cubic meters flowed through the filter during a 30-hour filter run.

	Known	Unknown
Flow, cu m	= 6000 cu m	Flow, *L*/sec
Time, hr	= 30 hr	

Calculate the flow through the filter in liters per second.

$$\text{Flow, } L\text{/sec} = \frac{(\text{Total Flow, cu m})(1000\ L\text{/cu m})}{(\text{Filter Run, hr})(60 \text{ min/hr})(60 \text{ sec/min})}$$

$$= \frac{(6000 \text{ cu m})(1000\ L\text{/cu m})}{(30 \text{ hr})(60 \text{ min/hr})(60 \text{ sec/min})}$$

$$= 55.6\ L\text{/sec}$$

EXAMPLE 27

Determine the Unit Filter Run Volume (UFRV) for a filter eight-meters long and five-meters wide if the volume of water filtered between backwash cycles is eight megaliters.

	Known	Unknown
Length, m	= 8 m	UFRV, *L*/sq m
Width, m	= 5 m	
Volume Filter, M*L*	= 8 M*L*	

Calculate the Unit Filter Run Volume in liters per square meter of filter surface area.

$$\text{UFRV, } L\text{/sq m} = \frac{\text{Volume Filtered, } L}{\text{Filter Surface Area, sq m}}$$

$$= \frac{8{,}000{,}000\ L}{(8 \text{ m})(5 \text{ m})}$$

$$= 200{,}000\ L\text{/sq m}$$

$$\text{or} \qquad = 200 \text{ cu m/sq m}$$

EXAMPLE 28

Determine the Unit Filter Run Volume (UFRV) for a filter if the filtration rate was two millimeters per second during a 46-hour filter run.

	Known	Unknown
Filtration Rate, mm/sec	= 2 mm/sec	UFRV, *L*/sq m
Filter Run, hr	= 46 hr	

Calculate the Unit Filter Run Volume in liters per square meter of filter surface area.

$$\text{UFRV, } L\text{/sq m} = \frac{(\text{Filtration Rate, mm/sec})(\text{Filter Run, hr})(60 \text{ sec/min})(60 \text{ min/hr})(1000\ L\text{/cu m})}{1000 \text{ mm/m}}$$

$$= \frac{(2 \text{ mm/sec})(46 \text{ hr})(60 \text{ sec/min})(60 \text{ min/hr})(1000\ L\text{/cu m})}{1000 \text{ mm/m}}$$

$$= 331{,}220\ L\text{/sq m}$$

EXAMPLE 29

Calculate the backwash flow required in cubic meters per day to backwash a 7.5-meter wide by 9-meter long filter if the desired backwash flow rate is 0.8 cubic meters per day per square meter.

	Known	Unknown
Width, m	=7.5 m	Backwash Flow, cu m/day
Length, m	=9 m	
Backwash Rate, cu m/day/sq m	=0.8 cu m/day/sq m	

Calculate the backwash flow in cubic meters per day.

$$\text{Backwash Flow, cu m/day} = (\text{Filter Area, sq m})(\text{Backwash Rate, cu m/day/sq m})$$

$$= (7.5 \text{ m})(9 \text{ m})(0.8 \text{ cu m/day/sq m})$$

$$= 54 \text{ cu m/day}$$

EXAMPLE 30

Convert a filter backwash rate of 25 liters per minute per square meter to millimeters per minute of rise.

	Known	Unknown
Backwash, *L*/min/sq m	= 25 *L*/min/sq m	Backwash, mm/min

Convert the backwash rate from *L*/min/sq m to mm/min.

$$\text{Backwash, mm/min} = \frac{(\text{Backwash, } L\text{/min/sq m})(1000 \text{ mm/m})}{1000\ L\text{/cu m}}$$

$$= \frac{(25\ L\text{/min/sq m})(1000 \text{ mm/m})}{1000\ L\text{/cu m}}$$

$$= 25 \text{ mm/min}$$

EXAMPLE 31

Determine the volume or amount of water required to backwash a filter if the backwash flow rate is 600 liters per second when the backwash time is seven minutes.

	Known	Unknown
Backwash Flow Rate, *L*/sec	= 600 *L*/sec	Backwash Water, *L*
Backwash Time, min	= 7 min	

Calculate the volume of backwash water required in liters.

$$\text{Backwash Water, Liters} = (\text{Backwash Flow, } L\text{/sec})(\text{Backwash Time, min})(60 \text{ sec/min})$$

$$= (600\ L\text{/sec})(7 \text{ min})(60 \text{ sec/min})$$

$$= 252{,}000\ L$$

$$= 0.252 \text{ M}L$$

EXAMPLE 32

During a filter run the total volume of water filtered was 50 megaliters. When the filter was backwashed, 250,000 liters of water was used. Calculate the percent of the product or finished water used for backwashing.

Known	Unknown
Water Filtered, M*L* = 50 M*L*	Backwash, %
Backwash Water, *L* = 250,000 *L*	

Calculate the percent of water used for backwashing.

$$\text{Backwash, \%} = \frac{(\text{Backwash Water, } L)(100\%)}{(\text{Water Filtered, M}L)(1{,}000{,}000/\text{M})}$$

$$= \frac{(250{,}000\ L)(100\%)}{(50\ \text{M}L)(1{,}000{,}000/\text{M})}$$

$$= 0.5\%$$

A.156 Disinfection

EXAMPLE 33

Calculate the chlorine dose in mg/*L* when a chlorinator is set to feed eight kilograms of chlorine in 24 hours. The flow is two megaliters per day.

Known	Unknown
Chlorinator Setting, kg/24 hrs = 8 kg/day	Chlorine Dose, mg/*L*
Flow, M*L*/day = 2 M*L*/day	

Calculate the chlorine dose in milligrams per liter.

$$\text{Chlorine Dose, mg}/L = \frac{(\text{Chlorine Feed, kg/day})(1\text{ M mg/kg})}{\text{Flow, M}L/\text{day}}$$

$$= \frac{(8\text{ kg/day})(1\text{ M mg/kg})}{2\text{ M}L/\text{day}}$$

$$= 4\text{ mg}/L$$

EXAMPLE 34

Estimate the chlorine demand for a water in milligrams per liter if the chlorine dose is 2.9 mg/*L* and the chlorine residual is 0.6 mg/*L*.

Known	Unknown
Chlorine Dose, mg/*L* = 2.9 mg/*L*	Chlorine Demand, mg/*L*
Chlorine Residual, mg/*L* = 0.6 mg/*L*	

Estimate the chlorine demand of the water in milligrams per liter.

$$\text{Chlorine Demand, mg}/L = \text{Chlorine Dose, mg}/L - \text{Chlorine Residual, mg}/L$$

$$= 2.9\text{ mg}/L - 0.6\text{ mg}/L$$

$$= 2.3\text{ mg}/L$$

EXAMPLE 35

Calculate the kilograms of chlorine used to disinfect water if 600 liters of hypochlorite as a 2.5 percent chlorine solution was used.

Known	Unknown
Hypochlorite, *L* = 600 *L*	Chlorine, kg
Hypochlorite, % = 2.5%	

Calculate the kilograms of chlorine used

$$\text{Chlorine, kg} = \frac{(\text{Hypochlorite, } L)(1\text{ kg}/L)(\text{Hypochlorite, \%})}{100\%}$$

$$= \frac{(600\ L)(1\text{ kg}/L)(2.5\%)}{100\%}$$

$$= 15\text{ kg chlorine}$$

EXAMPLE 36

Estimate the flow pumped by a hypochlorinator in liters per minute if the hypochlorite solution is in a container with a diameter of 0.8 meters and the hypochlorite level drops 35 centimeters during a nine-hour period. The hypochlorinator operated continuously during the nine-hour period.

Known	Unknown
Diameter, m = 0.8 m	Hypochlorinator Flow, *L*/min
Drop, cm = 35 cm	
Time, hr = 9 hr	

Calculate the hypochlorinator flow in liters per second.

$$\text{Flow, } L/\text{min} = \frac{(\text{Container Area, sq m})(\text{Drop, m})(1000\ L/\text{cu m})}{(\text{Time, hr})(60\text{ min/hr})}$$

$$= \frac{(0.785)(0.8\text{ m})^2(35\text{ cm})(1000\ L/\text{cu m})}{(9\text{ hr})(100\text{ cm/m})(60\text{ min/hr})}$$

$$= 0.33\ L/\text{min}$$

EXAMPLE 37

Estimate the desired strength (as a percent chlorine) of a hypochlorite solution which is pumped by a hypochlorinator that delivers 0.45 cubic meters per day. The water being treated requires a chlorine dose of six kilograms of chlorine per day.

Known	Unknown
Hypochlorinator Flow, cu m/day =0.45 cu m/day	Hypochlorite Strength, %
Chlorine Required, kg/day =6 kg/day	

Estimate the desired hypochlorite strength as a percent chlorine.

$$\text{Hypochlorite Strength, \%} = \frac{(\text{Chlorine Required, kg/day})(100\%)}{((\text{Hypochlorinator Flow, cu m/day})(1000\ L/\text{cu m})(1\text{ kg}/L)}$$

$$= \frac{(6\text{ kg/day})(100\%)}{(0.45\text{ cu m/day})(1000\ L/\text{cu m})(1\text{ kg}/L)}$$

$$= 1.33\%$$

EXAMPLE 38

How many liters of water must be added to 40 liters of five percent hypochlorite solution to produce a 1.33 percent hypochlorite solution?

Known	Unknown
Hypochlorite, *L* = 40 *L*	Water Added, liters
Desired Hypo, % = 1.33%	
Actual Hypo, % = 5%	

Calculate the liters of water that must be added to produce a 1.33 percent hypochlorite solution.

$$\text{Water Added, } L \text{ (to hypochlorite solution)} = \frac{(\text{Hypo, } L)(\text{Hypo, \%}) - (\text{Hypo, } L)(\text{Desired Hypo, \%})}{\text{Desired Hypo, \%}}$$

$$= \frac{(40\ L)(5\%) - (40\ L)(1.33\%)}{1.33\%}$$

$$= \frac{200 - 53.2}{1.33}$$

$$= 110 \text{ liters}$$

A.157 Corrosion Control

EXAMPLE 39

Calculate the Driving Force Index (D.F.I.) of a water at 12°C having a TDS of 100 mg/*L*, a calcium hardness of 60 mg/*L* as $CaCO_3$ and a carbonate (CO_3^{2-}) level of 2 mg/*L* as $CaCO_3$. The K'_{sp} value for calcium carbonate ($CaCO_3$) is 6.683×10^{-9}.

Known		Unknown
Water Temp, °C	= 12°C	D.F.I.
TDS, mg/*L*	= 200 mg/*L*	
Ca Hardness, mg/*L*	= 60 mg/*L* as $CaCO_3$	
CO_3^{2-}, mg/*L*	= 2 mg/*L* as $CaCO_3$	
K'_{sp} for $CaCO_3$	= 6.683×10^{-9}	

Calculate the Driving Force Index (D.F.I.).

$$\text{D.F.I.} = \frac{[Ca^{2+}][CO_3^{2-}]}{K'_{sp} \times 10^{10}}$$

$$= \frac{[60 \text{ mg}/L][2 \text{ mg}/L]}{(6.683 \times 10^{-9})(10^{10})}$$

$$= 1.80$$

When the D.F.I. is greater than one, the water is supersaturated with calcium carbonate.

EXAMPLE 40

Find the pH_s of a water at 10°C having a TDS of 100 mg/*L*, alkalinity of 40 mg/*L* and a calcium hardness of 60 mg/*L*.

Known		Unknown
Water Temp, °C	= 10°C	pH_s
TDS, mg/*L*	= 100 mg/*L*	
Alky, mg/*L*	= 40 mg/*L*	
Ca Hardness, mg/*L*	= 60 mg/*L* as $CaCO_3$	

1. Find the formula values from the tables in Chapter 8, "Corrosion Control." From Table 8.3 for a water temperature of 10°C, A = 2.20

   From Table 8.4 for a TDS of 160 mg/*L*,

   B = 9.75

   From Table 8.5 for Alky of 40 mg/*L* and Ca of 60 mg/*L*,

   $\log(Ca^{2+}) = 1.48,$
   $\log(\text{Alky}) = 1.78.$

2. Calculate pH_s.

$$pH_s = A + B - \log(Ca^{2+}) - \log(\text{Alky})$$

$$= 2.20 + 9.75 - 1.48 - 1.78$$

$$= 8.69$$

EXAMPLE 41

Calculate the Langelier Index for a water with a calculated pH_s value of 8.69 and an actual pH of 8.5.

Known		Unknown
pH_s	= 8.69	Langelier Index
pH	= 8.5	

Calculate the Langelier Index.

$$\text{Langelier Index} = pH - pH_s$$

$$= 8.5 - 8.69$$

$$= -0.19$$

Since the Langelier Index is negative, the water is corrosive.

A.158 Plant Operation

EXAMPLE 42

Estimate the average use of chlorine in kilograms per day based on actual use of chlorine for one week as shown below.

Day	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Chlorine Use, kg	23	37	35	31	32	36	24

Known	Unknown
Chlorine Use, kg/day	Ave Chlorine Use, kg/day

Estimate the average chlorine use in kilograms of chlorine per day.

$$\text{Average Chlorine Use, kg/day} = \frac{\text{Sum of Chlorine Used Each Day, kg}}{\text{Total Time, days}}$$

$$= \frac{23 \text{ kg}+37 \text{ kg}+35 \text{ kg}+31 \text{ kg}+32 \text{ kg}+36 \text{ kg}+ 24 \text{ kg}}{7 \text{ days}}$$

$$= \frac{218 \text{ kg}}{7 \text{ days}}$$

$$= 31.1 \text{ kg/day}$$

EXAMPLE 43

A water treatment plant has five 68-kilogram chlorine cylinders in storage. The plant uses an average of 12 kilograms of chlorine per day. How many days' supply of chlorine is in storage?

Known		Unknown
Chlorine Cylinders	= 5 cylinders	Supply of Chlorine, days
Cylinder Wt, kg/cyl	= 68 kg/cyl	
Ave Use, kg/day	= 12 kg/day	

Calculate the available supply of chlorine in storage in days.

$$\text{Supply of Chlorine, days} = \frac{(\text{Cylinder Wt, kg/cyl})(\text{No. of cylinders})}{\text{Ave Use, kg/day}}$$

$$= \frac{(68 \text{ kg/cyl})(5 \text{ cylinders})}{12 \text{ kg/day}}$$

$$= 28 \text{ days}$$

A.159 Laboratory Procedures

EXAMPLE 44

Convert the temperature of water from 65° Fahrenheit to degrees Celsius.

Known	Unknown
Temp. °F = 65°F	Temp. °C

Change 65°F to degrees Celsius.

$$\begin{aligned}\text{Temperature, °C} &= \frac{5}{9}(\text{°F} - 32\text{°F})\\ &= \frac{5}{9}(65\text{°F} - 32\text{°F})\\ &= 18.3\text{°C}\end{aligned}$$

EXAMPLE 45

Convert a water temperature of 12°Celsius to degrees Fahrenheit.

Known	Unknown
Temp, °C = 12°C	Temp, °F

Change 12°C to degrees Fahrenheit.

$$\begin{aligned}\text{Temperature, °F} &= \frac{9}{5}(\text{°C}) + 32\text{°F}\\ &= \frac{9}{5}(12\text{°C}) + 32\text{°F}\\ &= 53.6\text{°F}\end{aligned}$$

EXAMPLE 46

Results from a five-tube three dilution most probable number (MPN) fermentation-tube test are given below. Calculate the MPN per 100 *mL*.

Sample, *mL*	10	1	0.1
Number of Positive	3	1	0

Known	Unknown
Results of Fermentation tube test	MPN/100 *mL*

Calculate the MPN per 100 *mL*.

$$\begin{aligned}\text{MPN/100 } mL &= \frac{(\text{No. of positive tubes})(100)}{\sqrt{\begin{bmatrix}mL \text{ sample in}\\ \text{negative tubes}\end{bmatrix}\begin{bmatrix}mL \text{ sample in}\\ \text{all tubes}\end{bmatrix}}}\\ &= \frac{(4)(100)}{\sqrt{[(2)(10\ mL)+(4)(1\ mL)+5\ (0.1\ mL)]\,[(5)(10\ mL)+(5)(1\ mL)+(5)(0.1\ mL)]}}\\ &= \frac{400}{\sqrt{(24.5)(55.5)}}\\ &= 10.8\\ \text{or}\quad &= 11 \text{ MPN/100 } mL\end{aligned}$$

NOTE: See Example 47 of Section A.139, "Laboratory Procedures," for examples of how to calculate the mean, median and geometric mean.

WATER ABBREVIATIONS

ac	acre
ac-ft	acre-feet
af	acre feet
amp	ampere
°C	degrees Celsius
cfm	cubic feet per minute
cfs	cubic feet per second
Ci	Curie
cm	centimeter
cu ft	cubic feet
cu in	cubic inch
cu m	cubic meter
cu yd	cubic yard
°F	degrees Fahrenheit
ft	feet or foot
ft-lb/min	foot-pounds per minute
g	gravity
gal	gallon
gal/day	gallons per day
gm	gram
GPD	gallons per day
GPM	gallons per minute
gpg	grains per gallon
gr	grain
ha	hectare
HP	horsepower
hr	hour
in	inch
k	kilo
kg	kilogram
km	kilometer
kN	kilonewton
kW	kilowatt
kWh	kilowatt-hour
L	liter
lb	pound
lbs/sq in	pounds per square inch
m	meter
M	mega
M	million
mg	milligram
mg/*L*	milligram per liter
MGD	million gallons per day
m*L*	milliliter
min	minute
mm	millimeter
N	Newton
ohm	ohm
Pa	Pascal
pCi	picoCurie
psf	pounds per square foot
psi	pounds per square inch
psig	pounds per square inch gage
ppb	parts per billion
ppm	parts per million
sec	second
sq ft	square feet
sq in	square inches
W	watt

WATER WORDS

A Summary of the Words Defined

in

WATER TREATMENT PLANT OPERATION

and

WATER SUPPLY SYSTEM OPERATION

PROJECT PRONUNCIATION KEY

by Warren L. Prentice

The Project Pronunciation Key is designed to aid you in the pronunciation of new words. While this Key is based primarily on familiar sounds, it does not attempt to follow any particular pronunciation guide. This Key is designed solely to aid operators in this program.

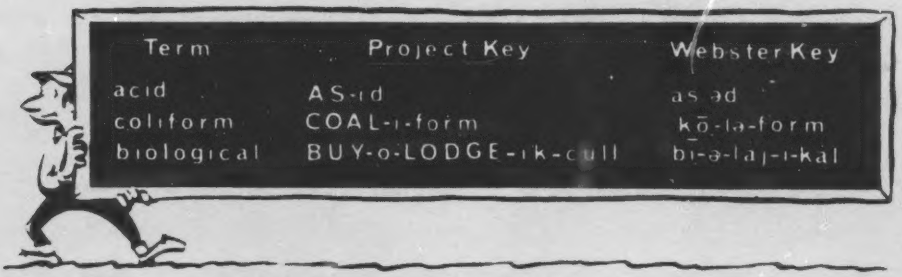
You may find it helpful to refer to other available sources for pronunciation help. Each current standard dictionary contains a guide to its own pronunciation Key. Each Key will be different from each other and from this Key. Examples of the differences between the Key used in this program and the *WEBSTER'S NEW WORLD DICTIONARY* "Key[1]", are shown below.

In using this Key, you should accent (say louder) the syllable which appears in capital letters. The following chart is presented to give examples of how to pronounce words using the Project Key.

	SYLLABLE				
Word	1st	2nd	3rd	4th	5th
acid	AS	id			
coagulant	co	AGG	you	lent	
biological	BUY	o	LODGE	ik	cull

The first word *ACID* has its first syllable accented. The second word, *COAGULANT*, has its second syllable accented. The third word, *BIOLOGICAL*, has its first and third syllables accented.

We hope you will find the Key useful in unlocking the pronunciation of any new word.



Term	Project Key	Webster Key
acid	AS-id	as əd
coliform	COAL-i-form	kō-lə-form
biological	BUY-o-LODGE-ik-cull	bī-ə-läj-i-kal

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[1] *The* WEBSTER'S NEW WORLD DICTIONARY, *Second College Edition, 1972, was chosen rather than an unabridged dictionary because of its availability to the operator. Other editions may be slightly different.*

WATER WORDS

ABC ABC

See ASSOCIATION OF BOARDS OF CERTIFICATION.

ABSORPTION (ab-SORP-shun) ABSORPTION

Taking in or soaking up of one substance into the body of another by molecular or chemical action (as tree roots absorb dissolved nutrients in the soil).

ACCURACY ACCURACY

How closely an instrument measures the true or actual value of the process variable being measured or sensed.

ACID RAIN ACID RAIN

Precipitation which has been rendered (made) acidic by airborne pollutants.

ACIDIC (uh-SID-ick) ACIDIC

The condition of water or soil which contains a sufficient amount of acid substances to lower the pH below 7.0.

ACIDIFIED (uh-SID-uh-FIE-d) ACIDIFIED

The addition of an acid (usually nitric or sulfuric) to a sample to lower the pH below 2.0. The purpose of acidification is to "fix" a sample so it won't change until it is analyzed.

ACRE-FOOT ACRE-FOOT

A volume of water that covers one acre to a depth of one foot, or 43,560 cubic feet (1233.5 cubic meters).

ACTIVATED CARBON ACTIVATED CARBON

Adsorptive particles or granules of carbon usually obtained by heating carbon (such as wood). These particles or granules have a high capacity to selectively remove certain trace and soluble materials from water.

ADSORBATE (add-SORE-bait) ADSORBATE

The material being removed by the adsorption process.

ADSORBENT (add-SORE-bent) ADSORBENT

The material (activated carbon) that is responsible for removing the undesirable substance in the adsorption process.

ADSORPTION (add-SORP-shun) ADSORPTION

The collection of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

AERATION (air-A-shun) AERATION

The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

AEROBIC (air-O-bick) AEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is present in the water.

AGE TANK AGE TANK

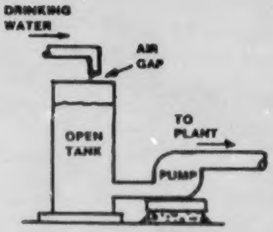
A tank used to store a chemical solution of known concentration for feed to a chemical feeder. Also called a DAY TANK.

AIR BINDING AIR BINDING

A situation where air enters the filter media. Air is harmful to both the filtration and backwash processes. Air can prevent the passage of water during the filtration process and can cause the loss of filter media during the backwash process.

AIR GAP AIR GAP

An open vertical drop, or vertical empty space, that separates a drinking (potable) water supply to be protected from another water system in a water treatment plant or other location. This open gap prevents the contamination of drinking water by backsiphonage or backflow because *there is no way raw water or any other water can reach* the drinking water.



AIR PADDING AIR PADDING

Pumping dry air into a container to assist with the withdrawal of a liquid or to force a liquefied gas such as chlorine out of a container.

AIR STRIPPING AIR STRIPPING

A treatment process used to remove dissolved gases and volatile substances from water. Large volumes of air are bubbled through the water being treated to remove (strip out) the dissolved gases and volatile substances.

ALARM CONTACT ALARM CONTACT

A switch that operates when some pre-set low, high or abnormal condition exists.

ALGAE (Al-gee) ALGAE

Microscopic plants which contain chlorophyll and live floating or suspended in water. They also may be attached to structures, rocks or other submerged surfaces. Excess algal growths can impart tastes and odors to potable water. Algae produce oxygen during sunlight hours and use oxygen during the night hours. Their biological activities appreciably affect the pH and dissolved oxygen of the water.

ALGAL BLOOM (AL-gull) ALGAL BLOOM

Sudden, massive growths of microscopic and macroscopic plant life, such as green or blue-green algae, which develop in lakes and reservoirs.

ALGICIDE (AL-gi-SIDE) ALGICIDE

Any substance or chemical specifically formulated to kill or control algae.

ALIPHATIC HYDROXY ACIDS (AL-uh-FAT-ick) ALIPHATIC HYDROXY ACIDS

Organic acids with carbon atoms arranged in branched or unbranched open chains rather than in rings.

ALIQUOT (AL-li-kwot) ALIQUOT

Portion of a sample.

ALKALI (AL-ka-lie) ALKALI

Various soluble salts, principally of sodium, potassium, magnesium, and calcium, that have the property of combining with acids to form neutral salts and may be used in chemical water treatment processes.

ALKALINE (AL-ka-LINE) ALKALINE

The condition of water or soil which contains a sufficient amount of alkali substances to raise the pH above 7.0.

ALKALINITY (AL-ka-LIN-it-tee) ALKALINITY

The capacity of water to neutralize acids. This capacity is caused by the water's content of carbonate, bicarbonate, hydroxide, and occasionally borate, silicate, and phosphate. Alkalinity is expressed in milligrams per liter of equivalent calcium carbonate. Alkalinity is not the same as pH because water does not have to be strongly basic (high pH) to have a high alkalinity. Alkalinity is a measure of how much acid can be added to a liquid without causing a great change in pH.

ALLUVIAL (uh-LOU-vee-ul) ALLUVIAL

Relating to mud and/or sand deposited by flowing water. Alluvial deposits may occur after a heavy rain storm.

ALTERNATING CURRENT (A.C.) ALTERNATING CURRENT (A.C.)

An electric current that reverses its direction (positive/negative values) at regular intervals.

AMBIENT TEMPERATURE (AM-bee-ent) AMBIENT TEMPERATURE

Temperature of the surrounding air (or other medium). For example, temperature of the room where a gas chlorinator is installed.

AMERICAN WATER WORKS ASSOCIATION AMERICAN WATER WORKS ASSOCIATION

A professional organization for all persons working in the water utility field. For information on AWWA membership and publications, contact AWWA, 6666 W. Quincy Avenue, Denver, Colorado 80235.

AMPERAGE (AM-purr-age) AMPERAGE

The strength of an electric current measured in amperes. The amount of electric current flow, similar to the flow of water in gallons per minute.

AMPERE (AM-peer) AMPERE

The unit used to measure current strength. The current produced by an electromotive force of one volt acting through a resistance of one ohm.

AMPEROMETRIC (am-PURR-o-MET-rick) AMPEROMETRIC

Based on the electric current that flows between two electrodes in a solution.

AMPEROMETRIC TITRATION AMPEROMETRIC TITRATION

A means of measuring concentrations of certain substances in water (such as strong oxidizers) based on the electric current that flows during a chemical reaction. See TITRATE.

ANAEROBIC (AN-air-O-bick) ANAEROBIC

A condition in which "free" (atmospheric) or dissolved oxygen is *NOT* present in water.

ANALOG ANALOG

The readout of an instrument by a pointer (or other indicating means) against a dial or scale.

ANALYZER ANALYZER

A device which conducts periodic or continuous measurement of some factor such as chlorine, fluoride or turbidity. Analyzers operate by any of several methods including photocells, conductivity or complex instrumentation.

ANION (AN-EYE-en) ANION

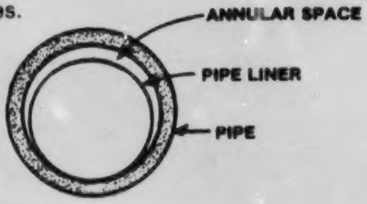
A negatively charged ion in an electrolyte solution, attracted to the anode under the influence of a difference in electrical potential. Chloride (Cl^-) is an anion.

ANIONIC POLYMER (AN-eye-ON-ick) ANIONIC POLYMER

A polymer having negatively charged groups of ions; often used as a filter aid and for dewatering sludges.

ANNULAR SPACE (AN-you-ler) ANNULAR SPACE

A ring-shaped space located between two circular objects, such as two pipes.



ANODE (an-O-d) ANODE

The positive pole or electrode of an electrolytic system, such as a battery. The anode attracts negatively charged particles or ions (anions).

APPROPRIATIVE APPROPRIATIVE

Water rights to or ownership of a water supply which is acquired for the beneficial use of water by following a specific legal procedure.

APPURTENANCE (uh-PURR-ten-nans) APPURTENANCE

Machinery, appliances, structures and other parts of the main structure necessary to allow it to operate as intended, but not considered part of the main structure.

AQUEOUS (A-kwee-us) AQUEOUS

Something made up of, similar to, or containing water; watery.

AQUIFER (ACK-wi-fer) AQUIFER

A natural underground layer of porous, water-bearing materials (sand, gravel) usually capable of yielding a large amount or supply of water.

ARTESIAN (are-TEE-zhun) ARTESIAN

Pertaining to groundwater, a well, or underground basin where the water is under a pressure greater than atmospheric and will rise above the level of its upper confining surface if given an opportunity to do so.

ASEPTIC (a-SEP-tick) ASEPTIC

Free from the living germs of disease, fermentation or putrefaction. Sterile.

ASSOCIATION OF BOARDS OF CERTIFICATION ASSOCIATION OF BOARDS OF CERTIFICATION

An international organization representing over seventy boards which certify the operators of waterworks and wastewater facilities. For information on ABC publications regarding the preparation of and how to study for operator certification examinations, contact ABC, P.O. Box 2266, Ames, Iowa 50010.

ASYMMETRIC (A-see-MET-rick) ASYMMETRIC

Not similar in size, shape, form or arrangement of parts on opposite sides of a line, point or plane.

ATOM ATOM

The smallest unit of a chemical element; composed of protons, neutrons and electrons.

AVAILABLE CHLORINE AVAILABLE CHLORINE

A measure of the amount of chlorine available in chlorinated lime, hypochlorite compounds, and other materials that are used as a source of chlorine when compared with that of elemental (liquid or gaseous) chlorine.

AVAILABLE EXPANSION AVAILABLE EXPANSION

The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called FREEBOARD.

AWWA AWWA

See AMERICAN WATER WORKS ASSOCIATION.

AXIAL TO IMPELLER AXIAL TO IMPELLER

The direction in which material being pumped flows around the impeller or flow parallel to the impeller shaft.

AXIS OF IMPELLER AXIS OF IMPELLER

An imaginary line running along the center of a shaft (such as an impeller shaft).

BACK PRESSURE BACK PRESSURE

A pressure that can cause water to backflow into the water supply when a user's water system is at a higher pressure than the public water system.

BACKFLOW BACKFLOW

A reverse flow condition, created by a difference in water pressures, which causes water to flow back into the distribution pipes of a potable water supply from any source or sources other than an intended source. Also see BACKSIPHONAGE.

BACKSIPHONAGE BACKSIPHONAGE

A form of backflow caused by a negative or below atmospheric pressure within a water system. Also see BACKFLOW.

BACKWASHING BACKWASHING

The process of reversing the flow of water back through the filter media to remove the entrapped solids.

BACTERIA (back-TEER-e-uh) BACTERIA

Bacteria are living organisms, microscopic in size, which usually consist of a single cell. Most bacteria use organic matter for their food and produce waste products as a result of their life processes.

BAFFLE BAFFLE

A flat board or plate, deflector, guide or similar device constructed or placed in flowing water or slurry systems to cause more uniform flow velocities, to absorb energy, and to divert, guide, or agitate liquids (water, chemical solutions, slurry).

BAILER (BAY-ler) BAILER

A 10- to 20-foot-long pipe equipped with a valve at the lower end. A bailer is used to remove slurry from the bottom or the side of a well as it is being drilled.

BASE METAL BASE METAL

A metal (such as iron) which reacts with dilute hydrochloric acid to form hydrogen. Also see NOBLE METAL.

BATCH PROCESS BATCH PROCESS

A treatment process in which a tank or reactor is filled, the water is treated or a chemical solution is prepared, and the tank is emptied. The tank may then be filled and the process repeated.

BIOCHEMICAL OXYGEN DEMAND BIOCHEMICAL OXYGEN DEMAND

BOD. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BIOLOGICAL GROWTH BIOLOGICAL GROWTH

The activity and growth of any and all living organisms.

BLANK BLANK

A bottle containing only dilution water or distilled water; the sample being tested is not added. Tests are frequently run on a SAMPLE and a BLANK and the differences are compared.

BOD (pronounce as separate letters) BOD

Biochemical **O**xygen **D**emand. The rate at which microorganisms use the oxygen in water while stabilizing decomposable organic matter under aerobic conditions. In decomposition, organic matter serves as food for the bacteria and energy results from its oxidation.

BONNET (BON-it) BONNET

The cover on a gate valve.

BRAKE HORSEPOWER BRAKE HORSEPOWER

(1) The horsepower required at the top or end of a pump shaft (input to a pump).

(2) The energy provided by a motor or other power source.

BREAKPOINT CHLORINATION BREAKPOINT CHLORINATION

Addition of chlorine to water until the chlorine demand has been satisfied. At this point, further additions of chlorine will result in a free residual chlorine that is directly proportional to the amount of chlorine added beyond the breakpoint.

BREAKTHROUGH BREAKTHROUGH

A crack or break in a filter bed allowing the passage of floc or particulate matter through a filter. This will cause an increase in filter effluent turbidity. A breakthrough can occur (1) when a filter is first placed in service, (2) when the effluent valve suddenly opens or closes, and (3) during periods of excessive head loss through the filter (including when the filter is exposed to negative heads).

BRINELLING (bruh-NEL-ing) BRINELLING

Tiny indentations (dents) high on the shoulder of the bearing race or bearing. A type of bearing failure.

BUFFER BUFFER

A solution or liquid whose chemical makeup neutralizes acids or bases without a great change in pH.

BUFFER CAPACITY BUFFER CAPACITY

A measure of the capacity of a solution or liquid to neutralize acids or bases. This is a measure of the capacity of water for offering a resistance to changes in pH.

C FACTOR C FACTOR

A factor or value used to indicate the smoothness of the interior of a pipe. The higher the C Factor, the smoother the pipe, the greater the carrying capacity, and the smaller the friction or energy losses from water flowing in the pipe. To calculate the C Factor, measure the flow, pipe diameter, distance between two pressure gages, and the friction or energy loss of the water between the gages.

$$\text{C Factor} = \frac{\text{Flow, GPM}}{193.75\,(\text{Diameter, ft})^{2.63}\,(\text{Slope})^{0.54}}$$

CAISSON (KAY-sawn) CAISSON

A structure or chamber which is usually sunk or lowered by digging from the inside. Used to gain access to the bottom of a stream or other body of water.

CALCIUM CARBONATE (CaCO$_3$) EQUIVALENT CALCIUM CARBONATE (CaCO$_3$) EQUIVALENT

An expression of the concentration of specified constituents in water in terms of their equivalence value to calcium carbonate. For example, the hardness in water which is caused by calcium, magnesium and other ions is usually described as calcium carbonate equivalent.

CALIBRATION CALIBRATION

A procedure which checks or adjusts an instrument's accuracy by comparison with a standard or reference.

CAPILLARY ACTION CAPILLARY ACTION

The movement of water through very small spaces due to molecular forces.

CAPILLARY FORCES CAPILLARY FORCES

The molecular forces which cause the movement of water through very small spaces.

CAPILLARY FRINGE CAPILLARY FRINGE

The porous material just above the water table which may hold water by capillarity (a property of surface tension that draws water upwards) in the smaller void spaces.

CARCINOGEN (car-SIN-o-jen) CARCINOGEN

Any substance which tends to produce cancer in an organism.

CATALYST (CAT-uh-LIST) CATALYST

A substance that changes the speed or yield of a chemical reaction without being consumed or chemically changed by the chemical reaction.

CATALYZE (CAT-uh-LIZE) CATALYZE

To act as a catalyst. Or, to speed up a chemical reaction.

CATALYZED (CAT-uh-LIZED) CATALYZED

To be acted upon by a catalyst.

CATHODE (KA-thow-d) CATHODE

The negative pole or electrode of an electrolytic cell or system. The cathode attracts positively charged particles or ions (cations).

CATHODIC PROTECTION (ca-THOD-ick) CATHODIC PROTECTION

An electrical system for prevention of rust, corrosion, and pitting of metal surfaces which are in contact with water or soil. A low-voltage current is made to flow through a liquid (water) or a soil in contact with the metal in such a manner that the external electromotive force renders the metal structure cathodic. This concentrates corrosion on auxiliary anodic parts which are deliberately allowed to corrode instead of letting the structure corrode.

CATION (CAT-EYE-en) CATION

A positively charged ion in an electrolyte solution, attracted to the cathode under the influence of a difference in electrical potential. Sodium ion (Na^+) is a cation.

CATIONIC POLYMER CATIONIC POLYMER

A polymer having positively charged groups of ions; often used as a coagulant aid.

CAVITATION (CAV-uh-TAY-shun) CAVITATION

The formation and collapse of a gas pocket or bubble on the blade of an impeller or the gate of a valve. The collapse of this gas pocket or bubble drives water into the impeller or gate with a terrific force that can cause pitting on the impeller or gate surface. Cavitation is accompanied by loud noises that sound like someone is pounding on the impeller or gate with a hammer.

CENTRATE CENTRATE

The water leaving a centifuge after most of the solids have been removed.

CENTRIFUGAL PUMP (sen-TRIF-uh-gull) CENTRIFUGAL PUMP

A pump consisting of an impeller fixed on a rotating shaft that is enclosed in a casing, and having an inlet and discharge connection. As the rotating impeller whirls the water around, centrifugal force builds up enough pressure to force the water through the discharge outlet.

CENTRIFUGE CENTRIFUGE

A mechanical device that uses centrifugal or rotational forces to separate solids from liquids.

CHECK VALVE **CHECK VALVE**

A special valve with a hinged disc or flap that opens in the direction of normal flow and is forced shut when flows attempt to go in the reverse or opposite direction of normal flow.

CHELATION (key-LAY-shun) **CHELATION**

A chemical complexing (forming or joining together) of metallic cations (such as copper) with certain organic compounds, such as EDTA (ethylene diamine tetracetic acid). Chelation is used to prevent the precipitation of metals (copper). Also see SEQUESTRATION.

CHLORAMINES (KLOR-uh-means) **CHLORAMINES**

Compounds formed by the reaction of hypochlorous acid (or aqueous chlorine) with ammonia.

CHLORINATION (KLOR-uh-NAY-shun) **CHLORINATION**

The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results (aiding coagulation and controlling tastes and odors).

CHLORINATOR (KLOR-uh-NAY-ter) **CHLORINATOR**

A metering device which is used to add chlorine to water.

CHLORINE DEMAND **CHLORINE DEMAND**

Chlorine demand is the difference between the amount of chlorine added to water and the amount of residual chlorine remaining after a given contact time. Chlorine demand may change with dosage, time, temperature, pH, and nature and amount of the impurities in the water.

$$\text{Chlorine Demand, mg}/L = \begin{matrix}\text{Chlorine}\\ \text{Applied, mg}/L\end{matrix} - \begin{matrix}\text{Chlorine}\\ \text{Residual, mg}/L\end{matrix}$$

CHLORINE REQUIREMENT **CHLORINE REQUIREMENT**

The amount of chlorine which is needed for a particular purpose. Some reasons for adding chlorine are reducing the number of coliform bacteria (Most Probable Number), obtaining a particular chlorine residual, or oxidizing some substance in the water. In each case a definite dosage of chlorine will be necessary. This dosage is the chlorine requirement.

CHLOROPHENOLIC (klor-o-FEE-NO-lick) **CHLOROPHENOLIC**

Chlorophenolic compounds are phenolic compounds (carbolic acid) combined with chlorine.

CHLOROPHENOXY (KLOR-o-fuh-KNOX-ee) **CHLOROPHENOXY**

A class of herbicides that may be found in domestic water supplies and cause adverse health effects. Two widely used chlorophenoxy herbicides are 2,4-D (2,4-Dichlorophenoxy acetic acid) and 2,4,5-TP (2,4,5-Trichlorophenoxy propionic acid (silvex)).

CHLORORGANIC (klor-or-GAN-nick) **CHLORORGANIC**

Organic compounds combined with chlorine. These compounds generally originate from, or are associated with, life processes such as those of algae in water.

CIRCLE OF INFLUENCE **CIRCLE OF INFLUENCE**

The circular outer edge of a depression produced in the water table by the pumping of water from a well. Also see CONE OF INFLUENCE and CONE OF DEPRESSION.

[SEE DRAWING ON PAGE 595]

CIRCUIT **CIRCUIT**

The complete path of an electric current, including the generating apparatus or other source; or, a specific segment or section of the complete path.

CIRCUIT BREAKER **CIRCUIT BREAKER**

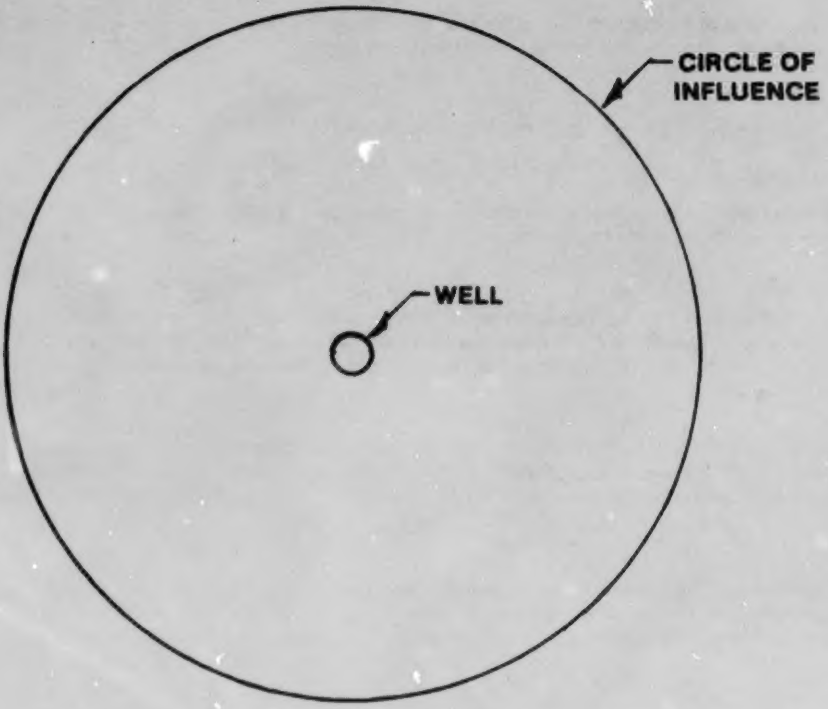
A safety device in an electrical circuit that automatically shuts off the circuit when it becomes overloaded. The device can be manually reset.

CISTERN (SIS-turn) **CISTERN**

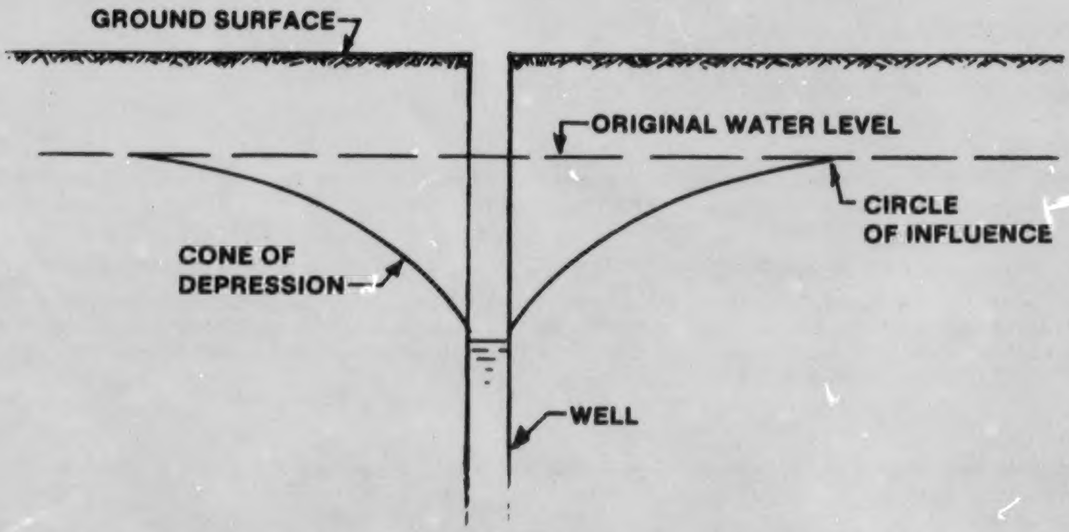
A small tank (usually covered) or a storage facility used to store water for a home or farm. Often used to store rain water.

CLARIFIER (KLAIR-uh-fire) **CLARIFIER**

A large circular or rectangular tank or basin in which water is held for a period of time, during which the heavier suspended solids settle to the bottom. Clarifiers are also called SETTLING BASINS and SEDIMENTATION BASINS.


CIRCLE OF INFLUENCE
WELL

TOP OR PLAN VIEW


GROUND SURFACE
ORIGINAL WATER LEVEL
CIRCLE OF INFLUENCE
CONE OF DEPRESSION
WELL

SIDE OR ELEVATION VIEW

CIRCLE OF INFLUENCE and CONE OF DEPRESSION

CLEAR WELL CLEAR WELL

A reservoir for the storage of filtered water of sufficient capacity to prevent the need to vary the filtration rate with variations in demand. Also used to provide chlorine contact time for disinfection.

COAGULANT AID COAGULANT AID

Any chemical or substance used to assist or modify coagulation.

COAGULANTS (co-AGG-you-lents) COAGULANTS

Chemicals that cause very fine particles to clump together into larger particles. This makes it easier to separate the solids from the water by settling, skimming, draining or filtering.

COAGULATION (co-AGG-you-LAY-shun) COAGULATION

The clumping together of very fine particles into larger particles caused by the use of chemicals (coagulants). The chemicals neutralize the electrical charges of the fine particles and cause destabilization of the particles. This clumping together makes it easier to separate the solids from the water by settling, skimming, draining, or filtering.

COLIFORM (COAL-i-form) COLIFORM

A group of bacteria found in the intestines of warm-blooded animals (including humans) and also in plants, soil, air and water. Fecal coliforms are a specific class of bacteria which only inhibit the intestines of warm-blooded animals. The presence of coliform bacteria is an indication that the water is polluted and may contain pathogenic organisms.

COLLOIDS (CALL-loids) COLLOIDS

Very small, finely divided solids (particles that do not dissolve) that remain dispersed in a liquid for a long time due to their small size and electrical charge. When most of the particles in water have a negative electrical charge, they tend to repel each other. This repulsion prevents the particles from clumping together, becoming heavier, and settling out.

COLORIMETRIC MEASUREMENT COLORIMETRIC MEASUREMENT

A means of measuring unknown chemical concentrations in water by measuring a sample's color intensity. The specific color of the sample, developed by addition of chemical reagents, is measured with a photoelectric colorimeter or is compared with "color standards" using, or corresponding with, known concentrations of the chemical.

COMBINED AVAILABLE RESIDUAL CHLORINE COMBINED AVAILABLE RESIDUAL CHLORINE

The concentration of residual chlorine which is combined with ammonia (NH_3) and/or organic nitrogen in water as a chloramine (or other chloro derivative) yet is still available to oxidize organic matter and utilize its bactericidal properties.

COMBINED RESIDUAL CHLORINATION COMBINED RESIDUAL CHLORINATION

The application of chlorine to water to produce combined available residual chlorine. This residual can be made up of monochloramines, dichloramines, and nitrogen trichloride.

COMPLETE TREATMENT COMPLETE TREATMENT

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called CONVENTIONAL FILTRATION.

COMPOSITE (come-PAH-zit) (PROPORTIONAL) SAMPLES COMPOSITE (PROPORTIONAL) SAMPLES

A composite sample is a collection of individual samples obtained at regular intervals, usually every one or two hours during a 24-hour time span. Each individual sample is combined with the others in proportion to the rate of flow when the sample was collected. The resulting mixture (composite sample) forms a representative sample and is analyzed to determine the average conditions during the sampling period.

COMPOUND COMPOUND

A substance composed of two or more elements whose composition is constant. For example, table salt (sodium chloride-NaCl) is a compound.

CONCENTRATION POLARIZATION CONCENTRATION POLARIZATION

(1) The ratio of the salt concentration in the membrane boundary layer to the salt concentration in the bulk stream. The most common and serious problem resulting from concentration polarization is the increasing tendency for precipitation of sparingly soluble salts and the deposition of particulate matter on the membrane surface.

(2) Used in corrosion studies to indicate a depletion of ions near an electrode.

(3) The basis for chemical analysis by a polarograph.

CONDUCTANCE CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called SPECIFIC CONDUCTANCE.

CONDUCTIVITY CONDUCTIVITY

A measure of the ability of a solution (water) to carry an electric current.

CONDUCTOR CONDUCTOR

A substance, body, device or wire that readily conducts or carries electrical current.

CONE OF DEPRESSION CONE OF DEPRESSION

The depression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF INFLUENCE.

[SEE DRAWING ON PAGE 595]

CONE OF INFLUENCE CONE OF INFLUENCE

The drepression, roughly conical in shape, produced in the water table by the pumping of water from a well. Also see CIRCLE OF INFLUENCE and CONE OF DEPRESSION.

[SEE DRAWING ON PAGE 595]

CONTACTOR CONTACTOR

An electrical switch, usually magnetically operated.

CONTAMINATION CONTAMINATION

The introduction into water of microorganisms, chemicals, toxic materials, wastes, or wastewater in a concentration that makes the water unfit for its next intended use.

CONTINUOUS SAMPLE CONTINUOUS SAMPLE

A flow of water from a particular place in a plant to the location where samples are collected for testing. This continuous stream may be used to obtain grab or composite samples. Frequently, several taps (faucets) will flow continuously in the laboratory to provide test samples from various places in a water treatment plant.

CONTROL LOOP CONTROL LOOP

The path through the control system between the sensor, which measures a process variable, and the controller, which controls or adjusts the process variable.

CONTROL SYSTEM CONTROL SYSTEM

A system which senses and controls its own operation on a close, continuous basis in what is called proportional (or modulating) control.

CONTROLLER CONTROLLER

A device which controls the starting, stopping, or operation of a device or piece of equipment.

CONVENTIONAL FILTRATION CONVENTIONAL FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation-flocculation, sedimentation and filtration. Also called COMPLETE TREATMENT. Also see DIRECT FILTRATION and IN-LINE FILTRATION.

CONVENTIONAL TREATMENT CONVENTIONAL TREATMENT

See CONVENTIONAL FILTRATION. Also called COMPLETE TREATMENT.

CORPORATION STOP CORPORATION STOP

A water service shutoff valve located at a street water main. This valve cannot be operated from the ground surface because it is buried and there is no valve box. Also called a CORPORATION COCK.

CORROSION CORROSION

The gradual decomposition or destruction of a material by chemical action, often due to an electrochemical reaction. Corrosion may be caused by (1) stray current electrolysis, (2) galvanic corrosion caused by dissimilar metals, or (3) differential-concentration cells. Corrosion starts at the surface of a material and moves inward.

CORROSION INHIBITORS CORROSION INHIBITORS

Substances that slow the rate of corrosion.

CORROSIVITY CORROSIVITY

An indication of the corrosiveness of a water. The corrosiveness of a water is described by the water's pH, alkalinity, hardness, temperature, total dissolved solids, and the Langelier Index.

COULOMB (COO-lahm) COULOMB

A measurement of the amount of electrical charge conveyed by an electric current of one ampere in one second. One coulomb equals about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons).

COUPON COUPON

A steel specimen inserted into water to measure the corrosiveness of water. The rate of corrosion is measured as the loss of weight of the coupon (in milligrams) per surface area (in square decimeters) exposed to the water per day.

10 decimeters = 1 meter = 100 centimeters

CROSS-CONNECTION CROSS-CONNECTION

A connection between a drinking (potable) water system and an unapproved water supply. For example, if you have a pump moving nonpotable water and hook into the drinking water system to supply water for the pump seal, a cross-connection or mixing between the two water systems can occur. This mixing may lead to contamination of the drinking water.

CURB STOP CURB STOP

A water service shutoff valve located in a water service pipe near the curb and between the water main and the building. This valve is usually operated by a wrench or valve key and is used to start or stop flows in the water service line to a building. Also called a "curb cock."

CURIE CURIE

A measure of radioactivity. One Curie of radioactivity is equivalent to 3.7×10^{10} or 37,000,000,000 nuclear disintegrations per second.

CURRENT CURRENT

A movement or flow of electricity. Water flowing in a pipe is measured in gallons per second past a certain point, not by the number of water molecules going past a point. Electric current is measured by the number of coulombs per second flowing past a certain point in a conductor. A coulomb is equal to about 6.25×10^{18} electrons (6,250,000,000,000,000,000 electrons). A flow of one coulomb per second is called one ampere, the unit of the rate of flow of current.

DATEOMETER (day-TOM-uh-ter) DATEOMETER

A small calendar disc attached to motors and equipment to indicate the year in which the last maintenance service was performed.

DAY TANK DAY TANK

A tank used to store a chemical solution of known concentration for feed to a chemical feeder. A day tank usually stores sufficient chemical solution to properly treat the water being treated for at least one day. Also called an AGE TANK.

DEAD END DEAD END

The end of a water main which is not connected to other parts of the distribution system by means of a connecting loop of pipe.

DECANT DECANT

To draw off the upper layer of liquid (water) after the heavier material (a solid or another liquid) has settled.

DECHLORINATION (dee-KLOR-uh-NAY-shun) DECHLORINATION

The deliberate removal of chlorine from water. The partial or complete reduction of residual chlorine by any chemical or physical process.

DECIBEL (DES-uh-bull) DECIBEL

A unit for expressing the relative intensity of sounds on a scale from zero for the average least perceptible sound to about 130 for the average level at which sound causes pain to humans.

DECOMPOSITION DECOMPOSITION

The conversion of chemically unstable materials to more stable forms by chemical or biological action. If organic matter decays when there is no oxygen present (anaerobic conditions or putrefaction), undesirable tastes and odors are produced. Decay of organic matter when oxygen is present (aerobic conditions) tends to produce much less objectionable tastes and odors.

DEFLUORIDATION (de-FLOOR-uh-DAY-shun) DEFLUORIDATION

The removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth.

DEGASIFICATION (DEE-GAS-if-uh-KAY-shun) DEGASIFICATION

A water treatment process which removes dissolved gases from the water. The gases may be removed by either mechanical or chemical treatment methods or a combination of both.

DEMINERALIZATION (DEE-MIN-er-al-uh-ZAY-shun) DEMINERALIZATION

A treatment process which removes dissolved minerals (salts) from water.

DENSITY (DEN-sit-tee) DENSITY

A measure of how heavy a substance (solid, liquid or gas) is for its size. Density is expressed in terms of weight per unit volume, that is, grams per cubic centimeter or pounds per cubic feet. The density of water (at 4°C or 39°F) is 1.0 gram per cubic centimeter or about 62.4 pounds per cubic foot.

DESALINIZATION (DEE-SAY-leen-uh-ZAY-shun) DESALINIZATION

The removal of dissolved salts (such as sodium chloride, NaCl) from water by natural means (leaching) or by specific water treatment processes.

DESICCANT (DESS-uh-kant) DESICCANT

A drying agent which is capable of removing or absorbing moisture from the atmosphere in a small enclosure.

DESICCATION (DESS-uh-KAY-shun) DESICCATION

A process used to thoroughly dry air; to remove virtually all moisture from air.

DESICCATOR (DESS-uh-KAY-tor) DESICCATOR

A closed container into which heated weighing or drying dishes are placed to cool in a dry environment. The dishes may be empty or they may contain a sample. Desiccators contain a substance, such as anhydrous calcium chloride, which absorbs moisture and keeps the relative humidity near zero so that the dish or sample will not gain weight from absorbed moisture.

DESTRATIFICATION (de-STRAT-uh-fuh-KAY-shun) DESTRATIFICATION

The development of vertical mixing within a lake or reservoir to eliminate (either totally or partially) separate layers of temperature, plant, or animal life. This vertical mixing can be caused by mechanical means (pumps) or through the use of forced air diffusers which release air into the lower layers of the reservoir.

DETECTION LAG DETECTION LAG

The time period between the moment a change is made and the moment when such a change is finally sensed by the associated measuring instrument.

DETENTION TIME DETENTION TIME

(1) The theoretical (calculated) time required for a small amount of water to pass through a tank at a given rate of flow.

(2) The actual time in hours, minutes or seconds that a small amount of water is in a settling basin, flocculating basin or rapid-mix chamber. In storage reservoirs, detention time is the length of time entering water will be held before being drafted for use (several weeks to years, several months being typical).

$$\text{Detention Time, hr} = \frac{(\text{Basin Volume, gal})(24\ \text{hr/day})}{\text{Flow, gal/day}}$$

DEW POINT DEW POINT

The temperature to which air with a given quantity of water vapor must be cooled to cause condensation of the vapor in the air.

DEWATER DEWATER

(1) To remove or separate a portion of the water present in a sludge or slurry. To dry sludge so it can be handled and disposed of.

(2) To remove or drain the water from a tank or a trench.

DIATOMACEOUS EARTH (DYE-uh-toe-MAY-shus) DIATOMACEOUS EARTH

A fine, siliceous (made of silica) "earth" composed mainly of the skeletal remains of diatoms.

DIATOMS (DYE-uh-toms) DIATOMS

Unicellular (single cell), microscopic algae with a rigid (box-like) internal structure consisting mainly of silica.

DIGITAL READOUT DIGITAL READOUT

Use of numbers to indicate the value or measurement of a variable. The readout of an instrument by a direct, numerical reading of the measured value.

DILUTE SOLUTION DILUTE SOLUTION

A solution that has been made weaker usually by the addition of water.

DIMICTIC (die-MICK-tick) DIMICTIC

Lakes and reservoirs which freeze over and normally go through two stratification and two mixing cycles within a year.

DIRECT CURRENT (D.C.) DIRECT CURRENT (D.C.)

Electrical current flowing in one direction only and essentially free from pulsation.

DIRECT FILTRATION DIRECT FILTRATION

A method of treating water which consists of the addition of coagulant chemicals, flash mixing, coagulation, minimal flocculation, and filtration. The flocculation facilities may be omitted, but the physical-chemical reactions will occur to some extent. The sedimentation process is omitted. Also see CONVENTIONAL FILTRATION and IN-LINE FILTRATION.

DIRECT RUNOFF DIRECT RUNOFF

Water that flows over the ground surface or through the ground directly into streams, rivers, or lakes.

DISCHARGE HEAD DISCHARGE HEAD

The pressure (in pounds per square inch or psi) measured at the centerline of a pump discharge and very close to the discharge flange, converted into feet.

Discharge Head, ft = (Discharge Pressure, psi)(2.31 ft/psi)

DISINFECTION (dis-in-FECK-shun) DISINFECTION

The process designed to kill most microorganisms in water, including essentially all pathogenic (disease-causing) bacteria. There are several ways to disinfect, with chlorine being most frequently used in water treatment. Compare with STERILIZATION.

DISTILLATE (DIS-tuh-late) DISTILLATE

In the distillation of a sample, a portion is evaporated; the part that is condensed afterwards is the distillate.

DIVALENT (die-VAY-lent) DIVALENT

Having a valence of two, such as the ferrous ion, Fe^{2+}.

DIVERSION DIVERSION

Use of part of a stream flow as a water supply.

DPD (pronounce as separate letters) DPD

A method of measuring the chlorine residual in water. The residual may be determined by either titrating or comparing a developed color with color standards. DPD stands for N,N-diethyl-p-phenylene-diamine.

DRAFT DRAFT

(1) The act of drawing or removing water from a tank or reservoir.

(2) The water which is drawn or removed from a tank or reservoir.

DRAWDOWN DRAWDOWN

(1) The drop in the water table or level of water in the ground when water is being pumped from a well.

(2) The amount of water used from a tank or reservoir.

(3) The drop in the water level of a tank or reservoir.

DYNAMIC PRESSURE DYNAMIC PRESSURE

When a pump is operating, the vertical distance (in feet) from a reference point (such as a pump centerline) to the hydraulic grade line is the dynamic head.

Dynamic Pressure, psi = (Dynamic Head, ft) (0.433 psi/ft)

EDUCTOR (e-DUCK-ter) EDUCTOR

A hydraulic device used to create a negative pressure (suction) by forcing a liquid through a restriction, such as a Venturi. An eductor or aspirator (the hydraulic device) may be used in the laboratory in place of a vacuum pump. As an injector, it is used to produce vacuum for chlorinators.

EFFECTIVE RANGE EFFECTIVE RANGE

That portion of the design range (usually upper 90 percent) in which an instrument has acceptable accuracy. Also see RANGE and SPAN.

EFFECTIVE SIZE (E.S.) EFFECTIVE SIZE (E.S.)

The diameter of the particles in a granular sample (filter media) for which 10 percent of the total grains are smaller and 90 percent larger on a weight basis. Effective size is obtained by passing granular material through sieves with varying dimensions of mesh and weighing the material retained by each sieve. The effective size is also approximately the average size of the grains.

EFFLUENT (EF-loo-ent) EFFLUENT

Water or other liquid — raw, partially or completely treated — flowing *FROM* a reservoir, basin, treatment process or treatment plant.

EJECTOR EJECTOR

A device used to disperse a chemical solution into water being treated.

ELECTROCHEMICAL REACTION ELECTROCHEMICAL REACTION

Chemical changes produced by electricity (electrolysis) or the production of electricity by chemical changes (galvanic action). In corrosion, a chemical reaction is accompanied by the flow of electrons through a metallic path. The electron flow may come from an external force and cause the reaction, such as electrolysis caused by a D.C. (direct current) electric railway or the electron flow may be caused by a chemical reaction as in the galvanic action of a flashlight dry cell.

ELECTROCHEMICAL SERIES ELECTROCHEMICAL SERIES

A list of metals with the standard electrode potentials given in volts. The size and sign of the electrode potential indicates how easily these elements will take on or give up electrons, or corrode. Hydrogen is conventionally assigned a value of zero.

ELECTROLYSIS (ee-leck-TRAWL-uh-sis) ELECTROLYSIS

The decomposition of material by an outside electrical current.

ELECTROLYTE (ee-LECK-tro-LIGHT) ELECTROLYTE

A substance which dissociates (separates) into two or more ions when it is dissolved in water.

ELECTROLYTIC CELL (ee-LECK-tro-LIT-ick) ELECTROLYTIC CELL

A device in which the chemical decomposition of material causes an electric current to flow. Also, a device in which a chemical reaction occurs as a result of the flow of electric current. Chlorine and caustic (NaOH) are made from salt (NaCl) in eletrolytic cells.

ELECTROMOTIVE FORCE (E.M.F.) ELECTROMOTIVE FORCE (E.M.F.)

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See VOLTAGE.

ELECTROMOTIVE SERIES ELECTROMOTIVE SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the Galvanic Series. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

ELECTRON ELECTRON

An extremely small, negatively charged particle; the part of an atom that determines its chemical properties.

ELEMENT ELEMENT

A substance which cannot be separated into its constituent parts and still retain its chemical identity. For example, sodium (Na) is an element.

END BELLS END BELLS

Devices used to hold the rotor and stator of a motor in position.

END POINT **END POINT**

Samples are titrated to the end point. This means that a chemical is added, drop by drop, to a sample until a certain color change (blue to clear, for example) occurs. This is called the END POINT of the titration. In addition to a color change, an end point may be reached by the formation of a precipitate or the reaching of a specified pH. An end point may be detected by the use of an electronic device such as a pH meter.

ENDEMIC (en-DEM-ick) **ENDEMIC**

Something peculiar to a particular people or locality, such as a disease which is always present in the population.

ENDRIN (EN-drin) **ENDRIN**

A pesticide toxic to freshwater and marine aquatic life that produces adverse health effects in domestic water supplies.

ENERGY GRADE LINE (E.G.L.) **ENERGY GRADE LINE (E.G.L.)**

A line that represents the elevation of energy head of water flowing in a pipe, conduit or channel. The line is drawn above the hydraulic grade line (gradient) a distance equal to the velocity head ($V^2/2g$) of the water flowing at each section or point along the pipe or channel. Also see HYDRAULIC GRADE LINE.

[SEE DRAWING ON PAGE 603]

ENTERIC **ENTERIC**

Of intestinal origin, especially applied to wastes or bacteria.

ENTRAIN **ENTRAIN**

To trap bubbles in water either mechanically through turbulence or chemically through a reaction.

ENZYMES (EN-zimes) **ENZYMES**

Organic substances (produced by living organisms) which cause or speed up chemical reactions. Organic catalysts and/or biochemical catalysts.

E.P.A. **E.P.A.**

U.S. **E**nvironmental **P**rotection **A**gency.

EPIDEMIC (EP-uh-DEM-ick) **EPIDEMIC**

A disease that occurs in a large number of people in a locality at the same time and spreads from person to person.

EPIDEMIOLOGY (EP-uh-DE-me-ALL-o-gee) **EPIDEMIOLOGY**

A branch of medicine which studies epidemics (diseases which affect significant numbers of people during the same time period in the same locality). The objective of epidemiology is to determine the factors that cause epidemic diseases and how to prevent them.

EPILIMNION (EP-uh-LIM-knee-on) **EPILIMNION**

The upper layer of water in a thermally stratified lake or reservoir. This layer consists of the warmest water and has a fairly uniform (constant) temperature. The layer is readily mixed by wind action.

ESTER **ESTER**

A compound formed by the reaction between an acid and an alcohol with the elimination of a molecule of water.

EUTROPHIC (you-TRO-fick) **EUTROPHIC**

Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.

EUTROPHICATION (you-TRO-fi-KAY-shun) **EUTROPHICATION**

The increase in the nutrient levels of a lake or other body of water; this usually causes an increase in the growth of aquatic animal and plant life.

EVAPORATION **EVAPORATION**

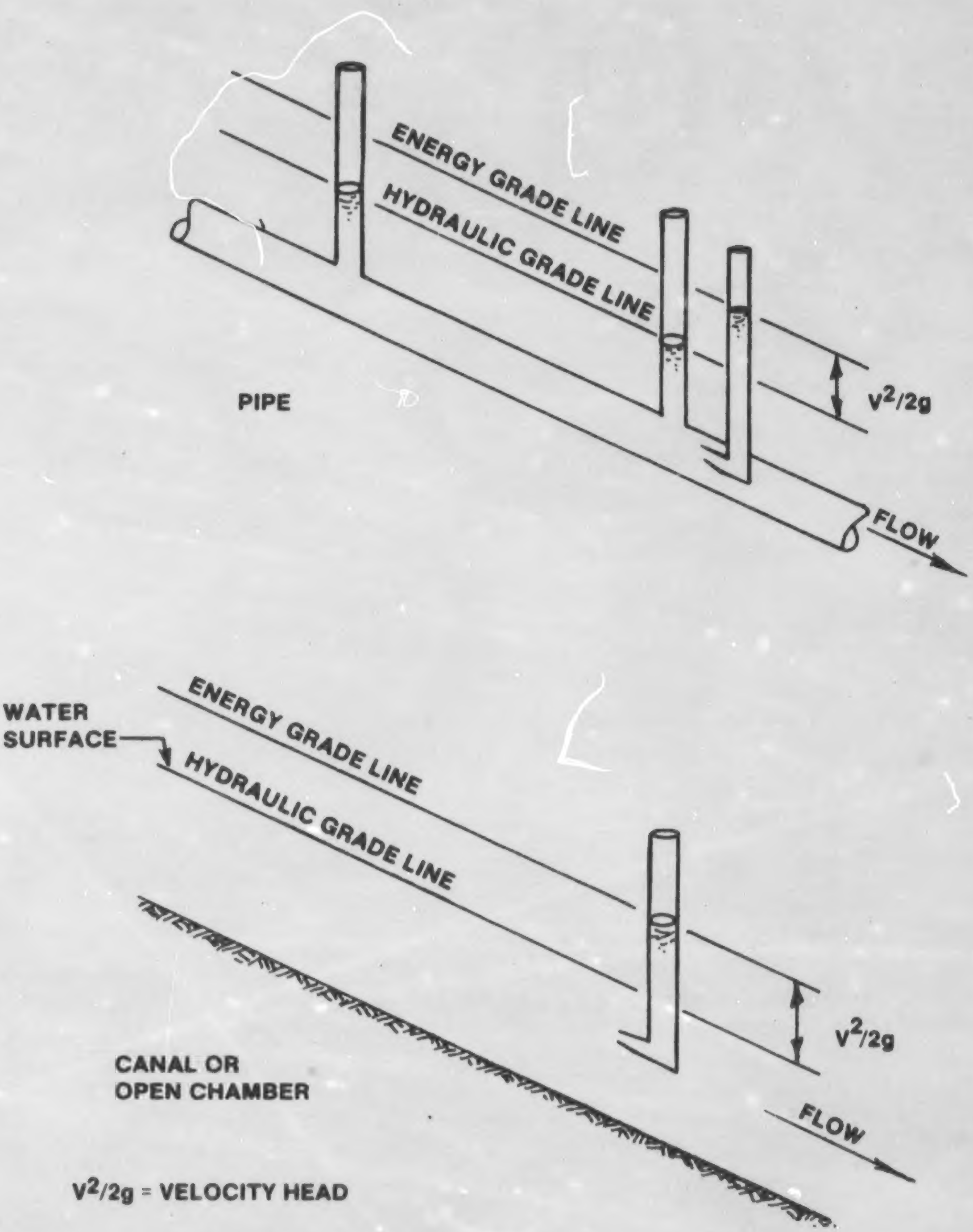
The process by which water or other liquid becomes a gas (water vapor or ammonia vapor).

EVAPOTRANSPIRATION (ee-VAP-o-TRANS-purr-A-shun) **EVAPOTRANSPIRATION**

The process by which water vapor passes into the atmosphere from living plants. Also called TRANSPIRATION.

FACULTATIVE (FACK-ul-TAY-tive) **FACULTATIVE**

Facultative bacteria can use either molecular (dissolved) oxygen or oxygen obtained from food material such as sulfate or nitrate ions. In other words, facultative bacteria can live under aerobic or anaerobic conditions.


ENERGY GRADE LINE
HYDRAULIC GRADE LINE
$V^2/2g$
PIPE
FLOW
WATER SURFACE
ENERGY GRADE LINE
HYDRAULIC GRADE LINE
$V^2/2g$
CANAL OR OPEN CHAMBER
FLOW
$V^2/2g$ = VELOCITY HEAD

ENERGY GRADE LINE and HYDRAULIC GRADE LINE

FEEDBACK **FEEDBACK**

The circulating action between a sensor measuring a process variable and the controller which controls or adjusts the process variable.

FINISHED WATER **FINISHED WATER**

Water that has passed through a water treatment plant; all the treatment processes are completed or "finished." This water is ready to be delivered to consumers. Also called PRODUCT WATER.

FIX, SAMPLE **FIX, SAMPLE**

A sample is "fixed" in the field by adding chemicals that prevent the water quality indicators of interest in the sample from changing before final measurements are performed later in the lab.

FLAGELLATES (FLAJ-el-LATES) **FLAGELLATES**

Microorganisms that move by the action of tail-like projections.

FLAME POLISHED **FLAME POLISHED**

Melted by a flame to smooth out irregularities. Sharp or broken edges of glass (such as the end of a glass tube) are rotated in a flame until the edge melts slightly and becomes smooth.

FLOC **FLOC**

Clumps of bacteria and particulate impurities that have come together and formed a cluster. Found in flocculation tanks and settling or sedimentation basins.

FLOCCULATION (FLOCK-you-LAY-shun) **FLOCCULATION**

The gathering together of fine particles after coagulation to form larger particles by a process of gentle mixing.

FLUIDIZED (FLEW-id-I-zd) **FLUIDIZED**

A mass of solid particles that is made to flow like a liquid by injection of water or gas is said to have been fluidized. In water treatment, a bed of filter media is fluidized by backwashing water through the filter.

FLUORIDATION (FLOOR-uh-DAY-shun) **FLUORIDATION**

The addition of a chemical to increase the concentration of fluoride ions in drinking water to a predetermined optimum limit to reduce the incidence (number) of dental caries (tooth decay) in children. Defluoridation is the removal of excess fluoride in drinking water to prevent the mottling (brown stains) of teeth.

FLUSHING **FLUSHING**

A method used to clean water distribution lines. Hydrants are opened and water with a high velocity flows through the pipes, removes deposits from the pipes, and flows out the hydrants.

FLUX **FLUX**

A flowing or flow.

FOOT VALVE **FOOT VALVE**

A special type of check valve located at the bottom end of the suction pipe on a pump. This valve opens when the pump operates to allow water to enter the suction pipe but closes when the pump shuts off to prevent water from flowing out of the suction pipe.

FREE AVAILABLE RESIDUAL CHLORINE **FREE AVAILABLE RESIDUAL CHLORINE**

That portion of the total available residual chlorine composed of dissolved chlorine gas (Cl_2), hypochlorous acid (HOCl), and/or hypochlorite ion (OCl^-) remaining in water after chlorination. This does not include chlorine that has combined with ammonia, nitrogen, or other compounds.

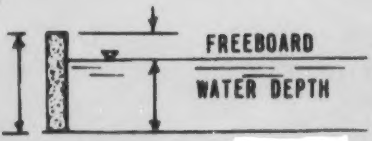
FREE RESIDUAL CHLORINATION **FREE RESIDUAL CHLORINATION**

The application of chlorine to water to produce a free available chlorine residual equal to at least 80 percent of the total residual chlorine (sum of free and combined available chlorine residual).

FREEBOARD **FREEBOARD**

(1) The vertical distance from the normal water surface to the top of the confining wall.

(2) The vertical distance from the sand surface to the underside of a trough in a sand filter. This distance is also called AVAILABLE EXPANSION.



FRICTION LOSSES FRICTION LOSSES

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls, and restrictions caused by fittings. Water flowing in a pipe loses pressure or energy as a result of friction losses. Also see HEAD LOSS.

FUNGI (FUN-ji) FUNGI

Mushrooms, molds, mildews, rusts, and smuts that are small non-chlorophyll-bearing plants lacking roots, stems and leaves. They occur in natural waters and grow best in the absence of light. Their decomposition may cause objectionable tastes and odors in water.

GAGE PRESSURE GAGE PRESSURE

The pressure within a closed container or pipe as measured with a gage. In contrast, absolute pressure is the sum of atmospheric pressure (14.7 lbs/sq in) *PLUS* pressure within a vessel (as measured by a gage). Most pressure gages read in "gage pressure" or psig (**p**ounds per **s**quare **i**nch **g**age pressure).

GALVANIC CELL GALVANIC CELL

An eletrolytic cell capable of producing electrical energy by electrochemical action. The decomposition of materials in the cell causes an electric (electron) current to flow from cathode to anode.

GALVANIC SERIES GALVANIC SERIES

A list of metals and alloys presented in the order of their tendency to corrode (or go into solution). Also called the ELECTROMOTIVE SERIES. This is a practical application of the theoretical ELECTROCHEMICAL SERIES.

GALVANIZE GALVANIZE

To coat a metal (especially iron or steel) with zinc. Galvanization is the process of coating a metal with zinc.

GARNET (GAR-nit) GARNET

A group of hard, reddish, glassy, mineral sands made up of silicates of base metals (calcium, magnesium, iron and manganese). Garnet has a higher density than sand.

GEOLOGICAL LOG GEOLOGICAL LOG

A detailed description of all underground features discovered during the drilling of a well (depth, thickness and type of formations).

GEOPHYSICAL LOG GEOPHYSICAL LOG

A record of the structure and composition of the earth encountered when drilling a well or similar type of test hole or boring.

GERMICIDE (GERM-uh-SIDE) GERMICIDE

A substance formulated to kill germs or microorganisms. The germicidal properties of chlorine make it an effective disinfectant.

GIARDIASIS (gee-are-DYE-uh-sis) GIARDIASIS

Intestinal disease caused by an infestation of Giardia flagellates.

GRAB SAMPLE GRAB SAMPLE

A single sample collected at a particular time and place which represents the composition of the water only at that time and place.

GRADE GRADE

(1) The elevation of the invert of the bottom of a pipeline, canal, culvert or similar conduit.

(2) The inclination or slope of a pipeline, conduit, stream channel, or natural ground surface; usually expressed in terms of the ratio or percentage of number of units of vertical rise or fall per unit of horizontal distance. A 0.5 percent grade would be a drop of one-half foot per hundred feet of pipe.

GRAVIMETRIC GRAVIMETRIC

A means of measuring unknown concentrations of water quality indicators in a sample by WEIGHING a precipitate or residue of the sample.

HARD WATER HARD WATER

Water having a high concentration of calcium and magnesium ions. A water may be considered hard if it has a hardness greater than the typical hardness of water from the region. Some textbooks define hard water as water with a hardness of more than 100 mg/*L* as calcium carbonate.

HARDNESS, WATER HARDNESS, WATER

A characteristic of water caused mainly by the salts of calcium and magnesium, such as bicarbonate, carbonate, sulfate, chloride and nitrate. Excessive hardness in water is undesirable because it causes the formation of soap curds, increased use of soap, deposition of scale in boilers, damage in some industrial processes, and sometimes causes objectionable tastes in drinking water.

HEAD HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

HEAD LOSS HEAD LOSS

The head, pressure or energy (they are the same) lost by water flowing in a pipe or channel as a result of turbulence caused by the velocity of the flowing water and the roughness of the pipe, channel walls or restrictions caused by fittings. Water flowing in a pipe loses head, pressure or energy as result of friction losses. Also see FRICTION LOSSES.

HEADER HEADER

A large pipe to which a series of smaller pipes are connected. Also called a MANIFOLD.

HEAT SENSOR HEAT SENSOR

A device that opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple which generates a minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a TEMPERATURE SENSOR.

HECTARE (HECK-tar) HECTARE

A measure of area in the metric system similar to an acre. One hectare is equal to 10,000 square meters and 2.4711 acres.

HEPATITIS (HEP-up-TIE-tis) HEPATITIS

Hepatitis is an inflammation of the liver usually caused by an acute viral infection. Yellow jaundice is one symptom of hepatitis.

HERBICIDE (HERB-uh-SIDE) HERBICIDE

A compound, usually a man-made organic chemical, used to kill or control plant growth.

HERTZ HERTZ

The number of complete electromagnetic cycles or waves in one second of an electrical or electronic circuit. Also called the frequency of the current. Abbreviated HZ.

HIGH-LINE JUMPERS HIGH-LINE JUMPERS

Pipes or hoses connected to fire hydrants and laid on top of the ground to provide emergency water service for an isolated portion of a distribution system.

HOSE BIB HOSE BIB

Faucet. A location in a water line where a hose is connected.

HTH (pronounce as separate letters) HTH

High **T**est **H**ypochlorite. Calcium hypochlorite or $Ca(OCl)_2$

HYDRATED LIME HYDRATED LIME

Limestone that has been "burned" and treated with water under controlled conditions until the calcium oxide portion has been converted to calcium hydroxide ($Ca(OH)_2$). Hydrated lime is quicklime combined with water. $CaO + H_2O \rightarrow Ca(OH)_2$. Also see QUICKLIME.

HYDRAULIC GRADE LINE (H.G.L.) HYDRAULIC GRADE LINE (H.G.L.)

The surface or profile of water flowing in an open channel or a pipe flowing partially full. If a pipe is under pressure, the hydraulic grade line is at the level water would rise to in a small vertical tube connected to the pipe. Also see ENERGY GRADE LINE.

[SEE DRAWING ON PAGE 603]

HYDRAULIC GRADIENT HYDRAULIC GRADIENT

The slope of the hydraulic grade line. This is the slope of the water surface in an open channel, the slope of the water surface of the groundwater table, or the slope of the water pressure for pipes under pressure.

HYDROGEOLOGIST (HI-dro-gee-ALL-uh-gist) HYDROGEOLOGIST

A person who studies and works with groundwater.

HYDROLOGIC CYCLE (HI-dro-LOJ-ick) HYDROLOGIC CYCLE

The process of evaporation of water into the air and its return to Earth by precipitation (rain or snow). This process also includes transpiration from plants, groundwater movement, and runoff into rivers, streams and the ocean. Also called the WATER CYCLE.

HYDROLYSIS (hi-DROLL-uh-sis) HYDROLYSIS

A chemical reaction in which a compound is converted into another compound by taking up water.

HYDROPHILIC (HI-dro-FILL-ick) HYDROPHILIC

Having a strong affinity (liking) for water. The opposite of HYDROPHOBIC.

HYDROPHOBIC (HI-dro-FOE-bick) HYDROPHOBIC

Having a strong aversion (dislike) for water. The opposite of HYDROPHILIC.

HYDROPNEUMATIC (HI-dro-new-MAT-ick) HYDROPNEUMATIC

A water system, usually small, in which a water pump is automatically controlled (started and stopped) by the air pressure in a compressed-air tank.

HYDROSTATIC PRESSURE (HI-dro-STAT-ick) HYDROSTATIC PRESSURE

(1) The pressure at a specific elevation exerted by a body of water at rest, or

(2) In the case of groundwater, the pressure at a specific elevation due to the weight of water at higher levels in the same zone of saturation.

HYPOCHLORINATION (HI-poe-KLOR-uh-NAY-shun) HYPOCHLORINATION

The application of hypochlorite compounds to water for the purpose of disinfection.

HYPOCHLORINATORS (HI-poe-KLOR-uh-NAY-tors) HYPOCHLORINATORS

Chlorine pumps, chemical feed pumps or devices used to dispense chlorine solutions made from hypochlorites such as bleach (sodium hypochlorite) or calcium hypochlorite into the water being treated.

HYPOCHLORITE (HI-poe-KLOR-ite) HYPOCHLORITE

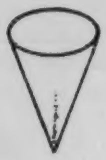
Chemical compounds containing available chlorine; used for disinfection. They are available as liquids (bleach) or solids (powder, granules and pellets). Salts of hypochlorous acid.

HYPOLIMNION (HI-poe-LIM-knee-on) HYPOLIMNION

The lowest layer in a thermally stratified lake or reservoir. This layer consists of colder, more dense water, has a constant temperature and no mixing occurs.

IMHOFF CONE IMHOFF CONE

A clear, cone-shaped container marked with graduations. The cone is used to measure the volume of settleable solids in a specific volume (usually one liter) of water.



IMPELLER IMPELLER

A rotating set of vanes in a pump designed to pump or lift water.

IMPERMEABLE (im-PURR-me-uh-BULL) IMPERMEABLE

Not easily penetrated. The property of a material or soil that does not allow, or allows only with great difficulty, the movement or passage of water.

INDICATOR (CHEMICAL) INDICATOR (CHEMICAL)

A substance that gives a visible change, usually of color, at a desired point in a chemical reaction, generally at a specified end point.

INDICATOR (INSTRUMENT) INDICATOR (INSTRUMENT)

A device which indicates the result of a measurement. Most indicators in the water utility field use either a fixed scale and movable indicator (pointer) such as a pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called a RECEIVER.

INFILTRATION (IN-fill-TRAY-shun) INFILTRATION

The gradual flow or movement of water into and through (to percolate or pass through) the pores of the soil. Also called PERCOLATION.

INFLUENT (IN-flu-ent) **INFLUENT**

Water or other liquid — raw or partially treated — flowing *INTO* a reservoir, basin, treatment process or treatment plant.

IN-LINE FILTRATION **IN-LINE FILTRATION**

The addition of chemical coagulants directly to the filter inlet pipe. The chemicals are mixed by the flowing water. Flocculation and sedimentation facilities are eliminated. This pretreatment method is commonly used in pressure filter installations. Also see CONVENTIONAL FILTRATION and DIRECT FILTRATION.

INORGANIC **INORGANIC**

Material such as sand, salt, iron, calcium salts and other mineral materials. Inorganic substances are of mineral origin, whereas organic substances are usually of animal or plant origin. Also see ORGANIC.

INPUT HORSEPOWER **INPUT HORSEPOWER**

The total power used in operating a pump and motor.

$$\text{Input Horsepower, HP} = \frac{(\text{Brake Horsepower,HP})(100\%)}{\text{Motor Efficiency, \%}}$$

INSECTICIDE **INSECTICIDE**

Any substance or chemical formulated to kill or control insects.

INTEGRATOR **INTEGRATOR**

A device or meter that continuously measures and calculates (adds) total flows in gallons, or million cubic feet, or some other unit of volume measurement. Also called a TOTALIZER.

INTERFACE **INTERFACE**

The common boundary layer between two substances such as water and a solid (metal); or between two fluids such as water and a gas (air); or between a liquid (water) and another liquid (oil).

INTERLOCK **INTERLOCK**

An electrical switch, usually magnetically operated. Used to interrupt all (local) power to a panel or device when the door is opened or the circuit exposed to service.

INTERNAL FRICTION **INTERNAL FRICTION**

Friction within a fluid (water) due to cohesive forces.

INTERSTICE (in-TUR-stuhz) **INTERSTICE**

A very small open space in a rock or granular material. Also called a void or void space. Also see PORE.

INVERT **INVERT**

The lowest point of the channel inside a pipe, conduit, or canal.

ION **ION**

An electrically charged atom, radical (such as SO_4^{2-}), or molecule formed by the loss or gain of one or more electrons.

IONIC CONCENTRATION **IONIC CONCENTRATION**

The concentration of any ion in solution, usually expressed in moles per liter.

IONIZATION (EYE-on-uh-ZAY-shun) **IONIZATION**

The splitting or dissociation (separation) of molecules into negatively and positively charged ions.

JAR TEST **JAR TEST**

A laboratory procedure that simulates a water treatment plant's coagulation/flocculation units with differing chemical doses and also energy of rapid mix, energy of slow mix, and settling time. The purpose of this procedure is to *ESTIMATE* the minimum or ideal coagulant dose required to achieve certain water quality goals. Samples of water to be treated are commonly placed in six jars. Various amounts of chemicals are added to each jar, stirred and the settling of solids is observed. The dose of chemicals that provides satisfactory settling removal of turbidity and/or color is the dose used to treat the water being taken into the plant at that time. When evaluating the results of a jar test, the operator should also consider the floc quality in the flocculation area and the floc loading on the filter.

JOGGING **JOGGING**

The frequent starting and stopping of an electric motor.

JOULE (jewel) JOULE

A measure of energy, work or quantity of heat. One joule is the work done when the point of application of a force of one newton is displaced a distance of one meter in the direction of force.

KILO KILO

(1) Kilogram.

(2) Kilometer.

(3) A prefix meaning "thousand" used in the metric system and other scientific systems of measurement.

KINETIC ENERGY KINETIC ENERGY

Energy possessed by a moving body of matter, such as water, as a result of its motion.

KJELDAHL NITROGEN (KELL-doll) KJELDAHL NITROGEN

Nitrogen in the form of organic proteins or their decomposition product ammonia, as measured by the Kjeldahl Method.

LANGELIER INDEX (L.I.) LANGELIER INDEX (L.I.)

An index reflecting the equilibrium pH of a water with respect to calcium and alkalinity. This index is used in stabilizing water to control both corrosion and the deposition of scale.

Langelier Index = $pH - ph_s$
where pH = actual pH of the water, and
pH_s = pH at which the water is just saturated with calcium carbonate

LAUNDERING WEIR (LAWN-der-ing weer) LAUNDERING WEIR

Sedimentation basin overflow weir. A plate with V-notches along the top to assure a uniform flow rate and avoid short-circuiting.

LAUNDERS (LAWN-ders) LAUNDERS

Sedimentation basin and filter discharge channels, consisting of overflow weir plates (in sedimentation basins) and conveying troughs.

LEVEL CONTROLS LEVEL CONTROLS

A float device (or pressure switch) which senses changes in a measured variable and opens or closes a switch in response to that change. In its simplest form, this control might be a floating ball connected mechanically to a switch or valve such as is used to stop water flow into a toilet when the tank is full.

LINDANE (LYNN-dane) LINDANE

A pesticide that causes adverse health effects in domestic water supplies and also is toxic to freshwater and marine aquatic life.

LINEARITY (LYNN-ee-AIR-it-ee) LINEARITY

How closely an instrument measures actual values of a variable through its effective range; a measure used to determine the accuracy of an instrument.

LITTORAL ZONE (LIT-or-al) LITTORAL ZONE

(1) That portion of a body of fresh water extending from the shoreline lakeward to the limit of occupancy of rooted plants.

(2) The strip of land along the shoreline between the high and low water levels.

LOGARITHM (LOG-a-rith-m) LOGARITHM

The exponent that indicates the power to which a number must be raised to produce a given number. For example: if $B^2 = N$, the 2 is the logarithm of N (to the base B), or $10^2 = 100$ and $\log_{10} 100 = 2$. Also abbreviated to "log."

M or MOLAR **M** or MOLAR

A molar solution consists of one gram molecular weight of a compound dissolved in enough water to make one liter of solution. A gram molecular weight is the molecular weight of a compound in grams. For example, the molecular weight of sulfuric acid (H_2SO_4) is 98. A one *M* solution of sulfuric acid would consist of 98 grams of H_2SO_4 dissolved in enough distilled water to make one liter of solution.

MACROSCOPIC (MACK-row-SKAWP-ick) ORGANISMS MACROSCOPIC ORGANISMS

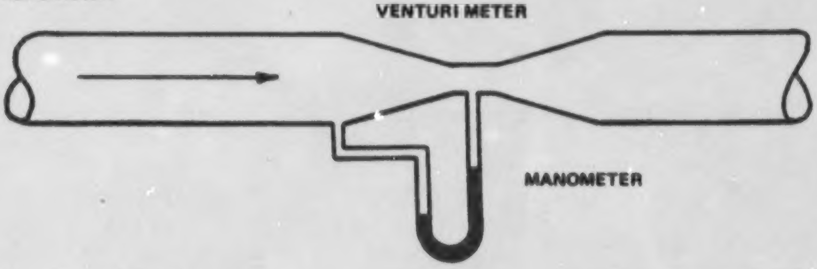
Organisms big enough to be seen by the eye without the aid of a microscope.

MANIFOLD MANIFOLD

A large pipe to which a series of smaller pipes are connected. Also called a HEADER.

MANOMETER (man-NAH-mut-ter) MANOMETER

An instrument for measuring pressure. Usually, a manometer is a glass tube filled with a liquid that is used to measure the difference in pressure across a flow-measuring device such as an orifice or Venturi meter. The instrument used to measure blood pressure is a type of manometer.



MAXIMUM CONTAMINANT LEVEL (MCL) MAXIMUM CONTAMINANT LEVEL (MCL)

See MCL.

MBAS MBAS

Methylene - **B**lue - **A**ctive **S**ubstances. These substances are used in surfactants or detergents.

MCL MCL

Maximum **C**ontaminant **L**evel. The largest allowable amount. MCLs for various water quality indicators are specified in the National Interim Primary Drinking Water Regulations (NIPDWR).

MEASURED VARIABLE MEASURED VARIABLE

A characteristic or component part that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

MECHANICAL JOINT MECHANICAL JOINT

A flexible device that joins pipes or fittings together by the use of lugs and bolts.

MEG MEG

A procedure used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEGGER.

MEGGER (from megohm) MEGGER

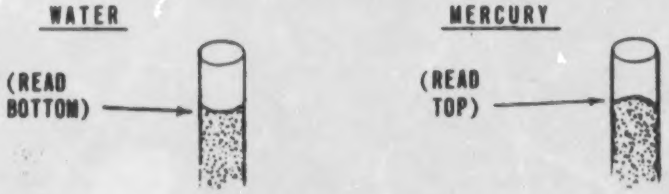
An instrument used for checking the insulation resistance on motors, feeders, buss bar systems, grounds, and branch circuit wiring. Also see MEG.

MEGOHM MEGOHM

Meg means one million, so 5 megohms means 5 million ohms. A Megger reads in millions of ohms.

MENISCUS (meh-NIS-cuss) MENISCUS

The curved top of a column of liquid (water, oil, mercury) in a small tube. When the liquid wets the sides of the container (as with water), the curve forms a valley. When the confining sides are not wetted (as with mercury), the curve forms a hill or upward bulge.



MESH MESH

One of the openings or spaces in a screen or woven fabric. The value of the mesh is usually given as the number of openings per inch. This value does not consider the diameter of the wire or fabric; therefore, the mesh number does not always have a definite relationship to the size of the hole.

MESOTROPHIC (MESS-o-TRO-fick) MESOTROPHIC

Reservoirs and lakes which contain moderate quantities of nutrients and are moderately productive in terms of aquatic animal and plant life.

METABOLISM (meh-TAB-uh-LIZ-um) METABOLISM

(1) The biochemical processes in which food is used and wastes are formed by living organisms.

(2) All biochemical reactions involved in cell formation and growth.

METALIMNION (MET-uh-LIM-knee-on) METALIMNION

The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the THERMOCLINE.

METHOXYCHLOR (meth-OXY-klor) METHOXYCHLOR

A pesticide which causes adverse health effects in domestic water supplies and is also toxic to freshwater and marine aquatic life. The chemical name for methoxychlor is 2,2-bis (p-methoxyphenol)-1,1,1-trichloroethane.

METHYL ORANGE ALKALINITY METHYL ORANGE ALKALINITY

A measure of the total alkalinity in a water sample. The alkalinity is measured by the amount of standard sulfuric acid required to lower the pH of the water to a pH level of 4.5, as indicated by the change in color of methyl orange from orange to pink. Methyl orange alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

mg/*L* mg/*L*

See MILLIGRAMS PER LITER.

MICROBIAL GROWTH (my-KROW-bee-ul) MICROBIAL GROWTH

The activity and growth of microorganisms such as bacteria, algae, diatoms, plankton and fungi.

MICRON (MY-kron) MICRON

A unit of length. One millionth of a meter or one thousandth of a millimeter. One micron equals 0.00004 of an inch.

MICROORGANISMS (MY-crow-OR-gan-IS-zums) MICROORGANISMS

Living organisms that can be seen individually only with the aid of a microscope.

MIL MIL

A unit of length equal to 0.001 of an inch. The diameter of wires and tubing is measured in mils, as is the thickness of plastic sheeting.

MILLIGRAMS PER LITER, mg/*L* MILLIGRAMS PER LITER, mg/*L*

A measure of the concentration by weight of a substance per unit volume. For practical purposes, one mg/*L* of a substance in fresh water is equal to one part per million parts (ppm). Thus a liter of water with a specific gravity of 1.0 weighs one million milligrams. If it contains 10 milligrams of calcium, the concentration is 10 milligrams per million milligrams, or 10 milligrams per liter (10 mg/*L*), or 10 parts of calcium per million parts of water, or 10 parts per million (10 ppm).

MILLIMICRON (MILL-uh-MY-kron) MILLIMICRON

A unit of length equal to $10^{-3}\mu$ (one thousandth of a micron), 10^{-6} millimeters, or 10^{-9} meters; correctly called a nanometer, nm.

MOLAR MOLAR

See **M** for MOLAR.

MOLE MOLE

The molecular weight of a substance, usually expressed in grams.

MOLECULAR WEIGHT MOLECULAR WEIGHT

The molecular weight of a compound in grams is the sum of the atomic weights of the elements in the compound. The molecular weight of sulfuric acid (H_2SO_4) in grams is 98.

Element	Atomic Weight	Number of Atoms	Molecular Weight
H	1	2	2
S	32	1	32
O	16	4	64
			98

MOLECULE (MOLL-uh-KULE) MOLECULE

The smallest division of a compound that still retains or exhibits all the properties of the substance.

MONOMER (MON-o-MER) MONOMER

A molecule of low molecular weight capable of reacting with identical or different monomers to form polymers.

MONOMICTIC (mo-no-MICK-tick) **MONOMICTIC**

Lakes and reservoirs which are relatively deep, do not freeze over during the winter months, and undergo a single stratification and mixing cycle during the year. These lakes and reservoirs usually become destratified during the mixing cycle, usually in the fall of the year.

MONOVALENT **MONOVALENT**

Having a valence of one, such as the cuprous (copper) ion, Cu^+.

MOST PROBABLE NUMBER (MPN) **MOST PROBABLE NUMBER (MPN)**

See MPN.

MOTILE (MO-till) **MOTILE**

Capable of self-propelled movement. A term that is sometimes used to distinguish between certain types of organisms found in water.

MOTOR EFFICIENCY **MOTOR EFFICIENCY**

The ratio of energy delivered by a motor to the energy supplied to it during a fixed period or cycle. Motor efficiency ratings will vary depending upon motor manufacturer and usually will range from 88.9 to 90.0 percent.

MPN (pronounce as separate letters) **MPN**

MPN is the Most Probable Number of coliform-group organisms per unit volume of sample water. Expressed as the number of organisms per 100 m*L* of sample water.

MUDBALLS **MUDBALLS**

Material that is approximately round in shape and varies from pea-sized up to two or more inches in diameter. This material forms in filters and gradually increases in size when not removed by the backwashing process.

MULTI-STAGE PUMP **MULTI-STAGE PUMP**

A pump that has more than one impeller. A single-stage pump has one impeller.

N or NORMAL **N or NORMAL**

A normal solution contains one gram equivalent weight of reactant (compound) per liter of solution. The equivalent weight of an acid is that weight which contains one gram atom of ionizable hydrogen or its chemical equivalent. For example, the equivalent weight of sulfuric acid (H_2SO_4) is 49 (98 divided by 2 because there are two replaceable hydrogen ions). A one *N* solution of sulfuric acid would consist of 49 grams of H_2SO_4 dissolved in enough water to make one liter of solution.

NATIONAL ENVIRONMENTAL TRAINING ASSOCIATION **NATIONAL ENVIRONMENTAL TRAINING ASSOCIATION**

A professional organizaiton devoted to serving the environmental trainer and promoting better operation of waterworks and pollution control facilities. For information on NETA membership and publications, contact NETA, P.O. Box 346, Valparaiso, Indiana 46383.

NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH **NATIONAL INSTITUTE OF OCCUPATIONAL SAFETY AND HEALTH**

See NIOSH.

NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS **NATIONAL INTERIM PRIMARY DRINKING WATER REGULATIONS**

Commonly referred to as NIPDWR.

NATIONAL SAFE DRINKING WATER REGULATIONS **NATIONAL SAFE DRINKING WATER REGULATIONS**

Commonly referred to as NSDWR.

NEPHELOMETRIC (NEFF-el-o-MET-rick) **NEPHELOMETRIC**

A means of measuring turbidity in a sample by using an instrument called a nephelometer. A nephelometer passes light through a sample and the amount of light deflected (usually at a 90-degree angle) is then measured.

NETA **NETA**

See **N**ational **E**nvironmental **T**raining **A**ssociation.

NEWTON **NEWTON**

A force which, when applied to a body having a mass of one kilogram, gives it an acceleration of one meter per second per second.

NIOSH NIOSH

The **N**ational **I**nstitute of **O**ccupational **S**afety and **H**ealth is an organization that tests and approves safety equipment for particular applications. NIOSH is the primary Federal agency engaged in research in the national effort to eliminate on-the-job hazards to the health and safety of working people. The NIOSH Publications Catalog contains a listing of NIOSH publications mainly on industrial hygiene and occupational health. To obtain a copy of the catalog, write to NIOSH Publications, 4676 Columbia Parkway, Cincinnati, Ohio 45226.

NIPDWR NIPDWR

National **I**nterim **P**rimary **D**rinking **W**ater **R**egulations.

NITROGENOUS (nye-TRAH-jen-us) NITROGENOUS

A term used to describe chemical compounds (usually organic) containing nitrogen in combined forms. Proteins and nitrates are nitrogenous compounds.

NOBLE METAL NOBLE METAL

A chemically inactive metal (such as gold). A metal that does not corrode easily and is much scarcer (and more valuable) than the so-called useful or base metals. Also see BASE METAL.

NOMINAL DIAMETER NOMINAL DIAMETER

An approximate measurement of the diameter of a pipe. Although the nominal diameter is used to describe the size or diameter of a pipe, it is usually not the exact inside diameter of the pipe.

NONIONIC POLYMER (NON-eye-ON-ick) NONIONIC POLYMER

A polymer that has no net eletrical charge.

NONPOINT SOURCE NONPOINT SOURCE

A runoff or discharge from a field or similar source. A point source refers to a discharge that comes out the end of a pipe.

NONPOTABLE (non-POE-tuh-bull) NONPOTABLE

Water that may contain objectionable pollution, contamination, minerals, or infective agents and is considered unsafe and/or unpalatable for drinking.

NORMAL NORMAL

See **N** for NORMAL.

NPDES PERMIT NPDES PERMIT

National **P**ollutant **D**ischarge **E**limination **S**ystem permit is the regulatory agency document designed to control all discharges of pollutants from point sources in U.S. waterways. NPDES permits regulate discharges into navigable waters from all point sources of pollution, including industries, municipal treatment plants, large agricultural feed lots and return irrigation flows.

NSDWR NSDWR

National **S**afe **D**rinking **W**ater **R**egulations.

NUTRIENT NUTRIENT

Any substance that is assimilated (taken in) by organisms and promotes growth. Nitrogen and phosphorous are nutrients which promote the growth of algae. There are other essential and trace elements which are also considered nutrients.

OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970 OCCUPATIONAL SAFETY AND HEALTH ACT OF 1970

See OSHA.

ODOR THRESHOLD ODOR THRESHOLD

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called THRESHOLD ODOR.

OFFSET (or DROOP) OFFSET

The difference between the actual value and the desired value (or set point); characteristic of proportional controllers that do not incorporate reset action.

OHM OHM

The unit of eletrical resistance. The resistance of a conductor in which one volt produces a current of one ampere.

OLFACTORY FATIGUE (oh-FAK-tore-ee) OLFACTORY FATIGUE

A condition in which a person's nose, after exposure to certain odors, is no longer able to detect the odor.

OLIGOTROPHIC (AH-lig-o-TRO-fick) OLIGOTROPHIC

Reservoirs and lakes which are nutrient poor and contain little aquatic plant or animal life.

ORGANIC ORGANIC

Substances that come from animal or plant sources. Organic substances always contain carbon. (Inorganic materials are chemical substances of mineral origin.) Also see INORGANIC.

ORGANICS ORGANICS

(1) A term used to refer to chemical compounds made from carbon molecules. These compounds may be natural materials (such as animal or plant sources) or man-made materials (such as synthetic organics). Also see ORGANIC.

(2) Any form of animal of plant life. Also see BACTERIA.

ORGANISM ORGANISM

Any form of animal or plant life. Also see BACTERIA.

ORIFICE (OR-uh-fiss) ORIFICE

An opening (hole) in a plate, wall or partition. An orifice flange or plate placed in a pipe consists of a slot or a calibrated circular hole smaller than the pipe diameter. The difference in pressure in the pipe above and at the orifice may be used to determine the flow in the pipe.

ORP ORP

Oxidation-**R**eduction **P**otential. The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

ORTHOTOLIDINE (or-tho-TOL-uh-dine) ORTHOTOLIDINE

Orthotolidine is a colorimetric indicator of chlorine residual. If chlorine is present, a yellow-colored compound is produced. This reagent is no longer approved for chemical analysis.

OSHA (O-shuh) OSHA

The Williams-Steiger **O**ccupational **S**afety and **H**ealth **A**ct of 1970 (OSHA) is a law designed to protect the health and safety of industrial workers and also the operators of water supply systems and treatment plants.

OSMOSIS (oz-MOE-sis) OSMOSIS

The passage of a liquid from a weak solution to a more concentrated solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). This process tends to equalize the conditions on either side of the membrane.

OVERALL EFFICIENCY, PUMP OVERALL EFFICIENCY, PUMP

The combined efficiency of a pump and motor together. Also called the WIRE-TO-WATER EFFICIENCY.

OVERDRAFT OVERDRAFT

The pumping of water from a groundwater basin or aquifer in excess of the supply flowing into the basin. This pumping results in a depletion or "mining" of the groundwater in the basin.

OVERFLOW RATE OVERFLOW RATE

One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called SURFACE LOADING.

$$\text{Overflow Rate, GDP/sq ft} = \frac{\text{Flow, gallons/day}}{\text{Surface Area, sq ft}}$$

OVERTURN OVERTURN

The almost spontaneous mixing of all layers of water in a reservoir or lake when the water temperature becomes similar from top to bottom. This may occur in the fall/winter when the surface waters cool to the same temperature as the bottom waters and also in the spring when the surface waters warm after the ice melts.

OXIDATION (ox-uh-DAY-shun) OXIDATION

Oxidation is the addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound. In the environment, organic matter is oxidized to more stable substances. The opposite of REDUCTION.

OXIDATION-REDUCTION POTENTIAL OXIDATION-REDUCTION POTENTIAL

The electrical potential required to transfer electrons from one compound or element (the oxidant) to another compound or element (the reductant); used as a qualitative measure of the state of oxidation in water treatment systems.

OXIDIZING AGENT OXIDIZING AGENT

Any substance, such as oxygen (O_2) or chlorine (Cl_2), that will readily add (take on) electrons. The opposite is a REDUCING AGENT.

OZONATION (O-zoe-NAY-shun) OZONATION

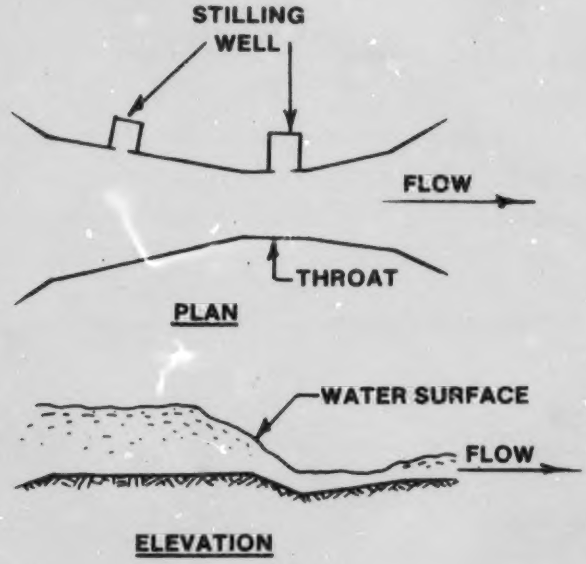
The application of ozone to water for disinfection or for taste and odor control.

PALATABLE (PAL-a-ta-ble) PALATABLE

Water at a desirable temperature that is free from objectionable tastes, odors, colors, and turbidity. Pleasing to the senses.

PARSHALL FLUME PARSHALL FLUME

A device used to measure the flow in an open channel. The flume narrows to a throat of fixed dimensions and then expands again. The rate of flow can be calculated by measuring the difference in head (pressure) before and at the throat of the flume.



PARTICLE COUNT PARTICLE COUNT

The results of a microscopic examination of treated water with a special "particle counter" which classifies suspended particles by number and size.

PARTICULATE (par-TICK-you-let) PARTICULATE

A very small solid suspended in water which can vary widely in size, shape, density, and electrical charge. Colloidal and dispersed particulates are artificially gathered together by the processes of coagulation and flocculation.

PARTS PER MILLION (PPM) PARTS PER MILLION (PPM)

Parts per million parts, a measurement of concentration on a weight or volume basis. This term is equivalent to milligrams per liter (mg/*L*) which is the preferred term.

PASCAL PASCAL

The pressure or stress of one newton per square meter. (Abbreviated Pa)

1 psi = 6895 Pa = 6.895 kN/sq m = 0.0703 kg/sq cm

PATHOGENIC ORGANISMS (path-o-JEN-ick) PATHOGENIC ORGANISMS

Organisms, including bacteria, viruses or cysts, capable of causing diseases (typhoid, cholera, dysentery) in a host (such as a person). There are many types of organisms which do *NOT* cause disease. These organisms are called non-pathogenic.

PATHOGENS (PATH-o-jens) PATHOGENS

Pathogenic or disease-causing organisms.

PERCENT SATURATION PERCENT SATURATION

The amount of a substance that is dissolved in a solution compared with the amount that could be dissolved in the solution, expressed as a percent.

$$\text{Percent Saturation, \%} = \frac{\text{Amount of Substance That is Dissolved}}{\text{Amount That Could Be Dissolved in Solution}} \times 100\%$$

PERCOLATING WATER (PURR-co-LAY-ting) PERCOLATING WATER

Water that passes through soil or rocks under the force of gravity.

PERCOLATION (PURR-ko-LAY-shun) PERCOLATION

The slow passage of water through a filter medium; or, the gradual penetration of soil and rocks by water.

PERIPHYTON (puh-RIF-uh-tawn) PERIPHYTON

Microscopic plants and animals that are firmly attached to solid surfaces under water such as rocks, logs, pilings and other structures.

PERMEABILITY (PURR-me-uh-BILL-uh-tee) PERMEABILITY

The property of a material or soil that permits considerable movement of water through it when it is saturated.

PERMEATE (PURR-me-ate) PERMEATE

To penetrate and pass through, as water penetrates and passes through soil and other porous materials.

PESTICIDE PESTICIDE

Any substance or chemical designed or formulated to kill or control weeds or animal pests. Also see ALGICIDE, HERBICIDE, INSECTICIDE,and RODENTICIDE.

pH (pronounce as separate letters) pH

pH is an expression of the intensity of the basic or acid condition of a liquid. Mathematically, pH is the logarithm (base 10) of the reciprocal of the hydrogen ion activity.

$$\text{pH} = \text{Log}\ \frac{1}{(H^+)}$$

The pH may range from 0 to 14, where 0 is most acid, 14 most basic, and 7 neutral. Natural waters usually have a pH between 6.5 and 8.5.

PHENOLIC COMPOUNDS (FEE-noll-LICK) PHENOLIC COMPOUNDS

Organic compounds that are derivatives of benzene.

PHENOLPHTHALEIN ALKALINITY (FEE-nol-THAY-leen) PHENOLPHTHALEIN ALKALINITY

The alkalinity in a water sample measured by the amount of standard acid required to lower the pH to a level of 8.3, as indicated by the change in color of phenolphthalein from pink to clear. Phenolphthalein alkalinity is expressed as milligrams per liter equivalent calcium carbonate.

PHOTOSYNTHESIS (foe-tow-SIN-thuh-sis) PHOTOSYNTHESIS

A process in which organisms, with the aid of chlorophyll (green plant enzyme), convert carbon dioxide and inorganic substances into oxygen and additional plant material, using sunlight for energy. All green plants grow by this process.

PHYTOPLANKTON (FI-tow-PLANK-ton) PHYTOPLANKTON

Small, usually microscopic plants (such as algae), found in lakes, reservoirs, and other bodies of water.

PICO PICO

A prefix used in the metric system and other scientific systems of measurement which means 10^{-12} or 0.000 000 000 001.

PICOCURIE PICOCURIE

A measure of radioactivity. One picoCurie of radioactivity is equivalent to 0.037 nuclear disintegrations per second.

PLAN VIEW PLAN VIEW

A diagram or photo showing a facility as it would appear when looking down on top of it.

PLANKTON PLANKTON

(1) Small, usually microscopic, plants (phytoplankton) and animals (zooplankton) in aquatic systems.

(2) All of the smaller floating, suspended or self-propelled organisms in a body of water.

PLUG FLOW PLUG FLOW

A type of flow that occurs in tanks, basins or reactors when a slug of water moves through a tank without ever dispersing or mixing with the rest of the water flowing through the tank.

PMCLs PMCLs

Primary Maximum Contaminant Levels. Primary MCLs for various water quality indicators are established to protect public health.

POINT SOURCE POINT SOURCE

A discharge that comes out of the end of a pipe. A nonpoint source refers to runoff or a discharge from a field or similar source.

POLE SHADER POLE SHADER

A copper bar circling the laminated iron core inside the coil of a magnetic starter.

POLLUTION POLLUTION

The impairment (reduction) of water quality by agricultural, domestic, or industrial wastes (including thermal and atomic wastes), to a degree that has an adverse effect on any beneficial use of water.

POLYELECTROLYTE (POLLY-ee-LECK-tro-lite) POLYELECTROLYTE

A high-molecular-weight (relatively heavy) substance having points of positive or negative electrical charges that is formed by either natural or man-made processes. Natural polyelectrolytes may be of biological origin or derived from starch products and cellulose derivatives. Man-made polyelectrolytes consist of simple substances that have been made into complex, high-molecular-weight substances. Used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. Often called a POLYMER.

POLYMER POLYMER

A chemical formed by the union of many monomers (a molecule of low molecular weight). Polymers are used with other chemical coagulants to aid in binding small suspended particles to larger chemical flocs for their removal from water. All polyelectrolytes are polymers, but not all polymers are polyelectrolytes.

PORE PORE

A very small open space in a rock or granular material. Also see INTERSTICE.

POSITIVE DISPLACEMENT PUMP POSITIVE DISPLACEMENT PUMP

A type of piston, diaphragm, gear or screw pump that delivers a constant volume with each stroke. Positive displacement pumps are used as chemical solution feeders.

POSTCHLORINATION POSTCHLORINATION

The addition of chlorine to the plant effluent, *FOLLOWING* plant treatment, for disinfection purposes.

POTABLE WATER (POE-tuh-bull) POTABLE WATER

Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

POWER FACTOR POWER FACTOR

The ratio of the true power passing through an electric circuit to the product of the voltage and amperage in the circuit. This is a measure of the lag or load of the current with respect to the voltage.

PPM PPM

See PARTS PER MILLION.

PRECHLORINATION PRECHLORINATION

The addition of chlorine at the headworks of the plant *PRIOR TO* other treatment processes mainly for disinfection and control of tastes, odors and aquatic growths. Also applied to aid in coagulation and settling.

PRECIPITATE (pre-SIP-uh-TATE) PRECIPITATE

(1) An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

(2) The separation from solution of an insoluble substance.

PRECIPITATION (pre-SIP-uh-TAY-shun) PRECIPITATION

(1) The process by which atmospheric moisture falls onto a land or water surface as rain, snow, hail, or other forms of moisture.

(2) The chemical transformation of a substance in solution into an insoluble form (precipitate).

PRECISION PRECISION

The ability of an instrument to measure a process variable and to repeatedly obtain the same result. The ability of an instrument to reproduce the same results.

PRECURSOR, THM (pre-CURSE-or) PRECURSOR, THM

Natural organic compounds found in all surface and groundwaters. These compounds *MAY* react with halogens (such as chlorine) to form trihalomethanes (try-HAL-o-METH-hanes) (THMs); they *MUST* be present in order for THMs to form.

PRESCRIPTIVE (pre-SKRIP-tive) PRESCRIPTIVE

Water rights which are acquired by diverting water and putting it to use in accordance with specified procedures. These procedures include filing a request to use unused water in a stream, river or lake with a state agency.

PRESSURE CONTROL PRESSURE CONTROL

A switch which operates on changes in pressure. Usually this is a diaphragm pressing against a spring. When the force on the diaphragm overcomes the spring pressure, the switch is actuated (activated).

PRESSURE HEAD PRESSURE HEAD

The vertical distance (in feet) equal to the pressure (in psi) at a specific point. The pressure head is equal to the pressure in psi times 2.31 ft/psi.

PRIMARY ELEMENT PRIMARY ELEMENT

An instrument which measures (senses) a physical condition or variable of interest. Floats and thermocouples are examples of primary elements. Also called a SENSOR.

PRIME PRIME

The action of filling a pump casing with water to remove the air. Most pumps must be primed before startup or they will not pump any water.

PROCESS VARIABLE PROCESS VARIABLE

A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

PRODUCT WATER PRODUCT WATER

Water that has passed through a water treatment plant. All the treatment processes are completed or finished. This water is the product from the water treatment plant and is ready to be delivered to the consumers. Also called FINISHED WATER.

PROFILE PROFILE

A drawing showing elevation plotted against distance, such as the vertical section or side view of a pipeline.

PRUSSIAN BLUE PRUSSIAN BLUE

A blue paste or liquid (often on a paper like carbon paper) used to show a contact area. Used to determine if gate valve seats fit properly.

PSIG PSIG

Pounds per **S**quare **I**nch **G**age pressure. The pressure within a closed container or pipe measured with a gage in pounds per square inch. See GAGE PRESSURE.

PUMPING WATER LEVEL PUMPING WATER LEVEL

The vertical distance in feet from the centerline of the pump discharge to the level of the free pool while water is being drawn from the pool.

PURVEYOR, WATER (purr-VAY-or) PURVEYOR, WATER

An agency or person that supplies water (usually potable water).

PUTREFACTION (PEW-truh-FACK-shun) PUTREFACTION

Biological decomposition of organic matter, with the production of ill-smelling and tasting products, associated with anaerobic (no oxygen present) conditions.

QUICKLIME QUICKLIME

A material that is mostly calcium oxide (CaO) or calcium oxide in natural association with a lesser amount of magnesium oxide. Quicklime is capable of combining with water, that is, becoming slaked. Also see HYDRATED LIME.

RADIAL TO IMPELLER RADIAL TO IMPELLER

Perpendicular to the impeller shaft. Material being pumped flows at a right angle to the impeller.

RADICAL RADICAL

A group of atoms that is capable of remaining unchanged during a series of chemical reactions. Such combinations (radicals) exist in the molecules of many organic compounds; sulfate (SO_4^{2-}) is an inorganic radical.

RANGE RANGE

The spread from minimum to maximum values that an instrument is designed to measure. Also see SPAN and EFFECTIVE RANGE.

RANNEY COLLECTOR RANNEY COLLECTOR

This water collector is constructed as a dug well from 12 to 16 feet (3.5 to 5 m) in diameter that has been sunk as a caisson near the bank of a river or lake. Screens are driven radially and approximately horizontally from this well into the sand and the gravel deposits underlying the river.

[SEE DRAWING ON PAGE 620]

RAW WATER RAW WATER

(1) Water in its natural state, prior to any treatment.

(2) Usually the water entering the first treatment process of a water treatment plant.

REAERATION (RE-air-A-shun) REAERATION

The introduction of air through forced air diffusers into the lower layers of the reservoir. As the air bubbles form and rise through the water, oxygen from the air dissolves into the water and replenishes the dissolved oxygen. The rising bubbles also cause the lower waters to rise to the surface where oxygen from the atmosphere is transferred to the water. This is sometimes called surface reaeration.

REAGENT (re-A-gent) REAGENT

A pure chemical substance that is used to make new products or is used in chemical tests to measure, detect, or examine other substances.

RECARBONATION (re-CAR-bun-NAY-shun) RECARBONATION

A process in which carbon dioxide is bubbled into the water being treated to lower the pH. The pH may also be lowered by the addition of acid. Recarbonation is the final stage in the lime-soda ash softening process. This process converts carbonate ions to bicarbonate ions and stabilizes the solution against the precipitation of carbonate compounds.

RECEIVER RECEIVER

A device which indicates the result of a measurement. Most receivers in the water utility field use either a fixed scale and movable indicator (pointer) such as pressure gage or a movable scale and movable indicator like those used on a circular-flow recording chart. Also called an INDICATOR.

RECORDER RECORDER

A device that creates a permanent record, on a paper chart or magnetic tape, of the changes of some measured variable.

REDUCING AGENT REDUCING AGENT

Any substance, such as base metal (iron) or the sulfide ion (S^{2-},) that will readily donate (give up) electrons. The opposite is an OXIDIZING AGENT.

REDUCTION (re-DUCK-shun) REDUCTION

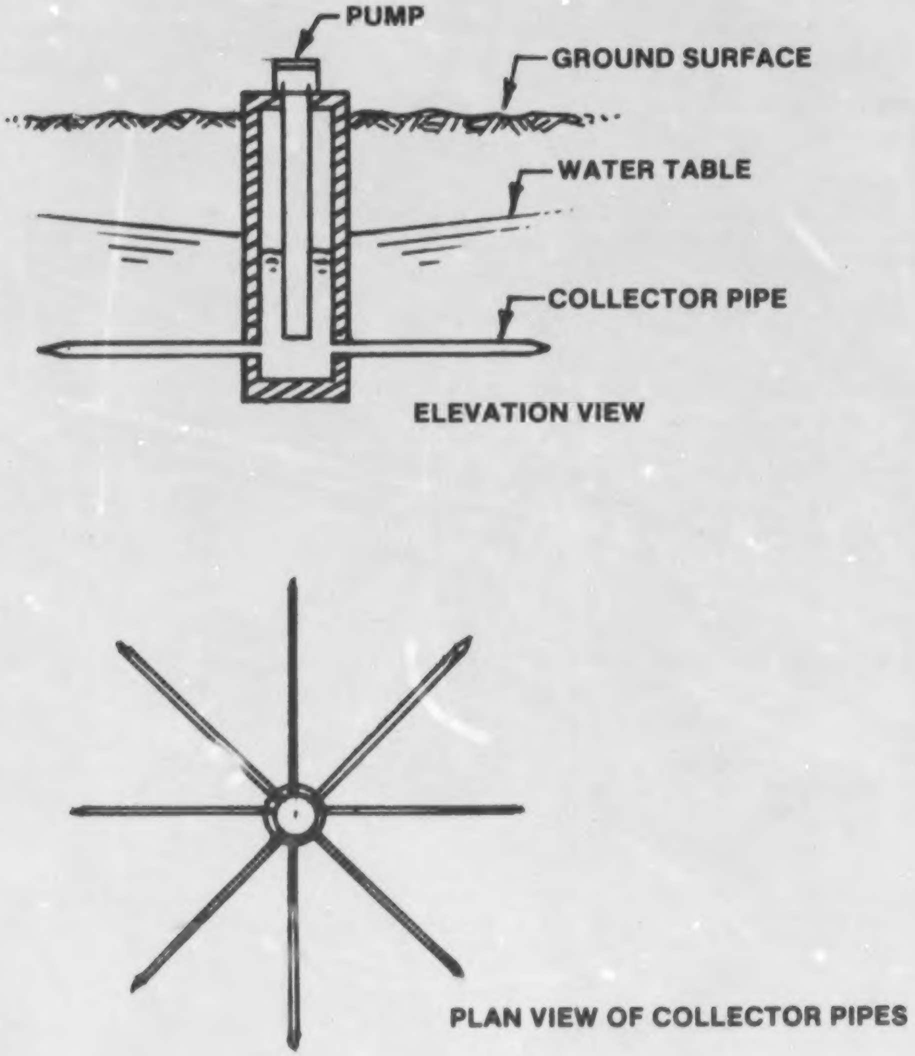
Reduction is the addition of hydrogen, removal of oxygen, or the addition of electrons to an element or compound. Under anaerobic conditions (no dissolved oxygen present), sulfur compounds are reduced to odor-producing hydrogen sulfide (H_2S) and other compounds. The opposite of OXIDATION.

REFERENCE REFERENCE

A physical or chemical quantity whose value is known exactly, and thus is used to calibrate or standardize instruments.

RELIQUEFACTION (re-LICK-we-FACK-shun) RELIQUEFACTION

The return of a gas to the liquid state; for example, a condensation of chlorine gas to return it to its liquid form by cooling.


PUMP
GROUND SURFACE
WATER TABLE
COLLECTOR PIPE
ELEVATION VIEW
PLAN VIEW OF COLLECTOR PIPES

RANNEY COLLECTOR

RANNEY COLLECTOR

REPRESENTATIVE SAMPLE REPRESENTATIVE SAMPLE

A portion of material or water that is as nearly identical in content and consistency as possible to that in the larger body of material or water being sampled.

RESIDUAL CHLORINE RESIDUAL CHLORINE

The amount of free and/or available chlorine remaining after a given contact time under specified conditions.

RESIDUE RESIDUE

The dry solids remaining after the evaporation of a sample of water or sludge. Also see TOTAL DISSOLVED SOLIDS.

RESPIRATION RESPIRATION

The process in which an organism uses oxygen for its life processes and gives off carbon dioxide.

REVERSE OSMOSIS (oz-MOE-sis) REVERSE OSMOSIS

The application of pressure to a concentrated solution which causes the passage of a liquid from the concentrated solution to a weaker solution across a semipermeable membrane. The membrane allows the passage of the solvent (water) but not the dissolved solids (solutes). The liquid produced is a demineralized water. Also see OSMOSIS.

RIPARIAN (ri-PAIR-ee-an) RIPARIAN

Water rights which are acquired together with title to the land bordering a source of surface water. The right to put to beneficial use surface water adjacent to your land.

RODENTICIDE (row-DENT-uh-SIDE) RODENTICIDE

Any substance or chemical used to kill or control rodents.

ROTAMETER (RODE-uh-ME-ter) ROTAMETER

A device used to measure the flow rate of gases and liquids. The gas or liquid being measured flows vertically up a tapered, calibrated tube. Inside the tube is a small ball or bullet-shaped float (it may rotate) that rises or falls depending on the flow rate. The flow rate may be read on a scale behind or on the tube by looking at the middle of the ball or at the widest part or top of the float.

ROTOR ROTOR

The rotating part of a machine. The rotor is surrounded by the stationary (non-moving) parts (stator) of the machine.

SACRIFICIAL ANODE SACRIFICIAL ANODE

An easily corroded material deliberately installed in a pipe or tank. The intent of such an installation is to give up (sacrifice) this anode to corrosion while the water supply facilities remain relatively corrosion free.

SAFE DRINKING WATER ACT SAFE DRINKING WATER ACT

Commonly referred to as SDWA. An Act passed by the U.S. Congress in 1974. The Act establishes a cooperative program among local, state and federal agencies to insure safe drinking water for consumers.

SAFE WATER SAFE WATER

Water that does not contain harmful bacteria, or toxic materials or chemicals. Water may have taste and odor problems, color and certain mineral problems and still be considered safe for drinking.

SAFE YIELD SAFE YIELD

The annual quantity of water that can be taken from a source of supply over a period of years without depleting the source parmanently (beyond its ability to be replenished naturally in "wet years").

SALINITY SALINITY

(1) The relative concentration of dissolved salts, usualy sodium chloride, in a given water.

(2) A measure of the concentration of dissolved mineral substances in water.

SANITARY SURVEY SANITARY SURVEY

A detailed evaluation and/or inspection of a source of water supply and all conveyances, storage, treatment and distribution facilities to insure its protection from all pollution sources.

SAPROPHYTES (SAP-row-FIGHTS) SAPROPHYTES

Organisms living on dead or decaying organic matter. They help natural decomposition of organic matter in water.

SATURATION SATURATION

The condition of a liquid (water) when it has taken into solution the maximum possible quantity of a given substance at a given temperature and pressure.

SATURATOR (SAT-you-RAY-tore) SATURATOR

A device which produces a fluoride solution for the fluoridation process. The device is usually a cylindrical container with granular sodium fluoride on the bottom. Water flows either upward or downward through the sodium fluoride to produce the fluoride solution.

SCFM SCFM

Cubic **F**eet of air per **M**inute at **S**tandard conditions of temperature, pressure and humidity (0°C / 14.7 psia / 50% relative humidity).

SDWA SDWA

See **S**AFE **D**RINKING **W**ATER **A**CT.

SECCHI DISC (SECK-key) SECCHI DISC

A flat, white disc lowered into the water by a rope until it is just barely visible. At this point, the depth of the disc from the water surface is the recorded Secchi disc transparency.

SEDIMENTATION (SED-uh-men-TAY-shun) SEDIMENTATION

A water treatment process in which solid particles settle out of the water being treated in a large clarifier or sedimentation basin.

SEIZE UP SEIZE UP

Seize up occurs when an engine overheats and a part expands to the point where the engine will not run. Also called "freezing."

SENSOR SENSOR

An instrument that measure (senses) a physical condition or variable of interest. Floats and thermocouples are examples of sensors. Also called a PRIMARY ELEMENT.

SEPTIC (SEP-tick) SEPTIC

A condition produced by bacteria when all oxygen supplies are depleted. If severe, bottom deposits and water turn black, give off foul odors, and the water has a greatly increased chlorine demand.

SEQUESTRATION (SEE-kwes-TRAY-shun) SEQUESTRATION

A chemical complexing (forming or joining together) of metallic cations (such as iron) with certain inorganic compounds, such as phosphate. Sequestration prevents the precipitation of the metals (iron). Also see CHELATION.

SERVICE PIPE SERVICE PIPE

The pipeline extending from the water main to the building served or to the consumer's system.

SET POINT SET POINT

The position at which the control or controller is set. This is the same as the desired value of the process variable.

SEWAGE SEWAGE

The used water and solids that flow from homes through sewers to a wastewater treatment plant. The preferred term is WASTEWATER.

SHOCK LOAD SHOCK LOAD

The arrival at a water treatment plant of raw water containing unusual amounts of algae, colloidal matter, color, suspended solids, turbidity, or other pollutants.

SHORT-CIRCUITING SHORT-CIRCUITING

A condition that occurs in tanks or basins when some of the water travels faster than the rest of the flowing water. This is usually undesirable since it may result in shorter contact, reaction, or settling times in comparison with the theoretical (calculated) or presumed detention times.

SIMULATE SIMULATE

To reproduce the action of some process, usually on a smaller scale.

SINGLE-STAGE PUMP SINGLE-STAGE PUMP

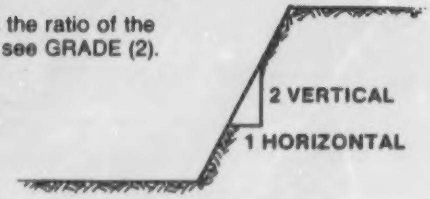
A pump that has only one impeller. A multi-stage pump has more than one impeller.

SLAKE SLAKE

To mix with water with a true chemical combination (hydrolysis) taking place, such as in the slaking of lime.

SLOPE SLOPE

The slope or inclination of a trench bottom or a trench side wall is the ratio of the vertical distance to the horizontal distance or "rise over run." Also see GRADE (2).



2:1 SLOPE

SLUDGE (sluj) SLUDGE

The settleable solids separated from water during processing.

SLURRY (SLUR-e) SLURRY

A watery mixture or suspension of insoluble (not dissolved) matter; a thin watery mud or any substance resembling it (such as a grit slurry or a lime slurry).

SMCLs SMCLs

Secondary **M**aximum **C**ontaminant **L**evels. Secondary MCLs for various water quality indicators are established to protect public welfare.

SNARL SNARL

Suggested **N**o **A**dverse **R**esponse **L**evel. The concentration of a chemical in water that is expected not to cause an adverse health effect.

SOFTWARE PROGRAMS SOFTWARE PROGRAMS

Computer programs; the list of instructions that tell a computer how to perform a given task or tasks.

SOFT WATER SOFT WATER

Water having a low concentration of calcium and magnesium ions. According to U.S. Geological Survey guidelines, soft water is water having a hardness of 60 milligrams per liter or less.

SOLENOID (SO-luh-noid) SOLENOID

A magnetically (electrical coil) operated mechanical device. Solenoids can operate a small valve or a switch.

SOLUTION SOLUTION

A liquid mixture of dissolved substances. In a solution it is impossible to see all the separate parts.

SOUNDING TUBE SOUNDING TUBE

A pipe or tube used for measuring the depths of water.

SPAN SPAN

The scale or range of values an instrument is designed to measure. Also see RANGE.

SPECIFIC CONDUCTANCE SPECIFIC CONDUCTANCE

A rapid method of estimating the dissolved-solids content of a water supply. The measurement indicates the capacity of a sample of water to carry an electrical current, which is related to the concentration of ionized substances in the water. Also called CONDUCTANCE.

SPECIFIC GRAVITY SPECIFIC GRAVITY

Weight of a particle, substance, or chemical solution in relation to the weight of water. Water has a specific gravity of 1.000 at 4°C (39°F). Particulates in raw water may have a specific gravity of 1.005 to 2.5.

SPECIFIC YIELD SPECIFIC YIELD

The quantity of water that a unit volume of saturated permeable rock or soil will yield when drained by gravity. Specific yield may be expressed as a ratio or as a percentage by volume.

SPOIL SPOIL

Excavated material such as soil from the trench of a water main.

SPORE SPORE

The reproductive body of an organism which is capable of giving rise to a new organism either directly or indirectly. A viable (able to live and grow) body regarded as the resting stage of an organism. A spore is usually more resistant to disinfectants and heat than most organisms.

SPRING LINE SPRING LINE

Theoretical center of a pipeline. Also, the guideline for laying a course of bricks.

STANDARD STANDARD

A physical or chemical quantity whose value is known exactly, and is used to calibrate or standardize instruments. Also see REFERENCE.

STANDARD METHODS STANDARD METHODS

STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER. A joint publication of the American Public Health Association, American Water Works Association, and the Water Pollution Control Federation which outlines the procedures used to analyze the impurities in water and wastewater.

STANDARD SOLUTION STANDARD SOLUTION

A solution in which the exact concentration of a chemical or compound is known.

STANDARDIZE STANDARDIZE

To compare with a standard.

(1) In wet chemistry, to find out the exact strength of a solution by comparing it with a standard of known strength.

(2) To set up an instrument or device to read a standard. This allows you to adjust the instrument so that it reads accurately, or enables you to apply a correction factor to the readings.

STARTERS STARTERS

Devices used to start up large motors gradually to avoid severe mechanical shock to a driven machine and to prevent disturbance to the electrical lines (causing dimming and flickering of lights).

STATIC HEAD STATIC HEAD

When water is not moving, the vertical distance (in feet) from a specific point to the water surface is the static head. (The static pressure in psi is the static head in feet times 0.433 psi/ft.) Also see DYNAMIC PRESSURE and STATIC PRESSURE.

STATIC PRESSURE STATIC PRESSURE

When water is not moving, the vertical distance (in feet) from a specific point to the water surface is the static head. The static pressure in psi is the static head in feet times 0.433 psi/ft. Also see DYNAMIC PRESSURE and STATIC HEAD.

STATIC WATER DEPTH STATIC WATER DEPTH

The vertical distance in feet from the centerline of the pump discharge down to the surface level of the free pool while no water is being drawn from the pool or water table.

STATIC WATER LEVEL STATIC WATER LEVEL

(1) The elevation or level of the water table in a well when the pump is not operating.

(2) The level or elevation to which water would rise in a tube connected to an artesian aquifer, or basin, or conduit under pressure.

STATOR STATOR

That portion of a machine which contains the stationary (non-moving) parts that surround the moving parts (rotor).

STERILIZATION (STARE-uh-luh-ZAY-shun) STERILIZATION

The removal or destruction of all microorganisms, including pathogenic and other bacteria, vegetative forms and spores. Compare with DISINFECTION.

STETHOSCOPE STETHOSCOPE

An instrument used to magnify sounds and convey them to the ear.

STRATIFICATION (STRAT-uh-fuh-KAY-shun) STRATIFICATION

The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir. Each layer has similar characteristics such as all water in the layer has the same temperature. Also see THERMAL STRATIFICATION.

SUBMERGENCE SUBMERGENCE

The distance between the water surface and the media surface in a filter.

SUCTION LIFT SUCTION LIFT

The *NEGATIVE* pressure [in feet (meters) of water or inches (centimeters) of mercury vacuum] on the suction side of the pump. The pressure can be measured from the centerline of the pump *DOWN TO* (lift) the elevation of the hydraulic grade line on the suction side of the pump.

SUPERCHLORINATION (SUE-per-KLOR-uh-NAY-shun) SUPERCHLORINATION

Chlorination with doses that are deliberately selected to produce free or combined residuals so large as to require dechlorination.

SUPERNATANT (sue-per-NAY-tent) SUPERNATANT

Liquid removed from settled sludge. Supernatant commonly refers to the liquid between the sludge on the bottom and the water surface of a basin or container.

SUPERSATURATED SUPERSATURATED

An unstable condition of a solution (water) in which the solution contains a substance at a concentration greater than the saturation concentration for the substance.

SURFACE LOADING SURFACE LOADING

One of the guidelines for the design of settling tanks and clarifiers in treatment plants. Used by operators to determine if tanks and clarifiers are hydraulically (flow) over- or underloaded. Also called OVERFLOW RATE.

$$\text{Surface Loading, GPD/sq ft} = \frac{\text{Flow, gallon/day}}{\text{Surface Area, sq ft}}$$

SURFACTANT (sir-FAC-tent) SURFACTANT

Abbreviation for surface-active agent. The active agent in detergents that possesses a high cleaning ability.

SURGE CHAMBER SURGE CHAMBER

A chamber or tank connected to a pipe and located at or near a valve that may quickly open or close or a pump that may suddenly start or stop. When the flow of water in a pipe starts or stops quickly, the surge chamber allows water to flow into or out of the pipe and minimize any sudden positive or negative pressure waves or surges in the pipe.

[SEE DRAWING ON PAGE 626]

SUSPENDED SOLIDS SUSPENDED SOLIDS

(1) Solids that either float on the surface or are suspended in water or other liquids, and which are largely removable by laboratory filtering.

(2) The quantity of material removed from water in a laboratory test, as prescribed in *STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER* and referred to as nonfilterable residue.

TCE TCE

See **T**RI**C**HLORO**E**THANE.

TDS TDS

See **T**OTAL **D**ISSOLVED **S**OLIDS.

TELEMETRY (tel-LEM-uh-tree) TELEMETRY

The electrical link between the transmitter and the receiver. Telephone lines are commonly used to serve as the electrical line.

TEMPERATURE SENSOR TEMPERATURE SENSOR

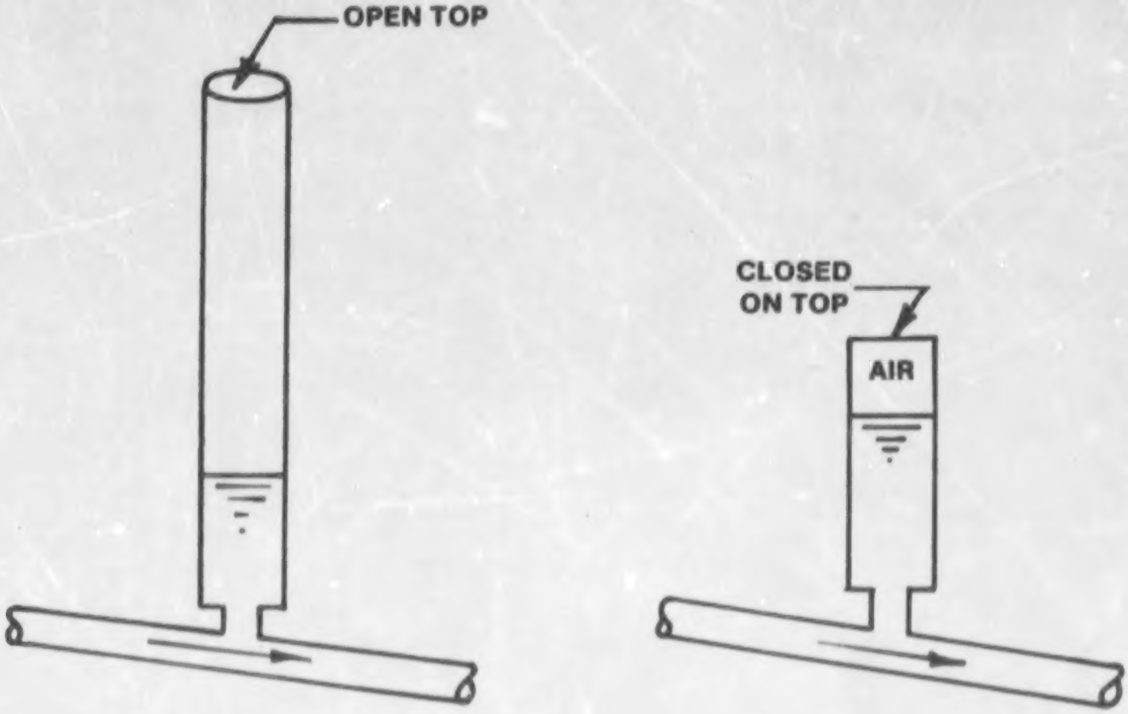
A device that opens and closes a switch in response to changes in the temperature. This device might be a metal contact, or a thermocouple that generates minute electrical current proportional to the difference in heat, or a variable resistor whose value changes in response to changes in temperature. Also called a HEAT SENSOR.

THERMAL STRATIFICATION (STRAT-uh-fuh-KAY-shun) THERMAL STRATIFICATION

The formation of layers of different temperatures in a lake or reservoir. Also see STRATIFICATION.

THERMOCLINE (THUR-moe-KLINE) THERMOCLINE

The middle layer in a thermally stratified lake or reservoir. In this layer there is a rapid decrease in temperature with depth. Also called the METALIMNION.


OPEN TOP
CLOSED ON TOP
AIR

TYPES OF SURGE CHAMBERS

THERMOCOUPLE THERMOCOUPLE

A heat-sensing device made of two conductors of different metals joined at their ends. An electric current is produced when there is a difference in temperature between the ends.

THM THM

See TRIHALOMETHANES.

THM PRECURSOR THM PRECURSOR

See PRECURSOR, THM.

THRESHOLD ODOR THRESHOLD ODOR

The minimum odor of a water sample that can just be detected after successive dilutions with odorless water. Also called ODOR THRESHOLD.

THRESHOLD ODOR NUMBER THRESHOLD ODOR NUMBER

TON. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.

THRUST BLOCK THRUST BLOCK

A mass of concrete or similar material appropriately placed around a pipe to prevent movement when the pipe is carrying water. Usually placed at bends and valve structures.

TIME LAG TIME LAG

The time required for processes and control systems to respond to a signal or to reach a desired level.

TIMER TIMER

A device for automatically starting or stopping a machine or other device at a given time.

TITRATE (TIE-trate) TITRATE

To *TITRATE* a sample, a chemical solution of known strength is added on a drop-by-drop basis until a certain color change, precipitate, or pH change in the sample is observed (end point). Titration is the process of adding the chemical reagent in increments until completion of the reaction, as signaled by the end point.

TOPOGRAPHY TOPOGRAPHY

The arrangement of hills and valleys in a geographic area.

TOTAL DISSOLVED SOLIDS (TDS) TOTAL DISSOLVED SOLIDS (TDS)

All of the dissolved solids in a water. TDS is measured on a sample of water that has passed through a very fine mesh filter to remove suspended solids. The water passing through the filter is evaporated and the residue represents the dissolved solids. Also see SPECIFIC CONDUCTANCE.

TOTAL DYNAMIC HEAD (TDH) TOTAL DYNAMIC HEAD (TDH)

When a pump is lifting or pumping water, the vertical distance (in feet) from the elevation of the energy grade line on the suction side of the pump to the elevation of the energy grade line on the discharge side of the pump.

TOTAL RESIDUAL CHLORINE TOTAL RESIDUAL CHLORINE

The amount of available chlorine remaining after a given contact time. The sum of the combined available residual chlorine and the free available residual chlorine. Also see RESIDUAL CHLORINE.

TOTALIZER TOTALIZER

A device or meter that continuously measures and calculates (adds) total flows in gallons, million gallons, cubic feet, or some other unit of volume measurement. Also called an INTEGRATOR.

TOXAPHENE (TOX-uh-FEEN) TOXAPHENE

A chemical that causes adverse health effects in domestic water supplies and also is toxic to freshwater and marine aquatic life.

TOXIC (TOX-ick) TOXIC

A substance which is poisonous to an organism.

TRANSDUCER (trans-DUE-sir) TRANSDUCER

A device which senses some varying condition and converts it to an electrical signal for transmission to some other device (a receiver) for processing or decision making.

TRANSMISSION LINES TRANSMISSION LINES

Pipelines that transport raw water from its source to a water treatment plant. After treatment, water is usually pumped into pipelines (transmission lines) that are connected to a distribution grid system.

TRANSMISSIVITY (TRANS-miss-SIV-it-tee) TRANSMISSIVITY

A measure of the ability to transmit (as in the ability of an aquifer to transmit water).

TRANSPIRATION (TRAN-spur-RAY-shun) TRANSPIRATION

The process by which water vapor is released to the atmosphere by living plants. This process is similar to people sweating. Also called EVAPOTRANSPIRATION.

TREMIE (TREH-me) TREMIE

A device used to place concrete or grout under water.

TRICHLOROETHANE (TCE) (try-KLOR-o-ETH-hane) TRICHLOROETHANE (TCE)

An organic chemical used as a cleaning solvent that causes adverse health effects in domestic water supplies.

TRIHALOMETHANES (tri-HAL-o-METH-hanes) TRIHALOMETHANES

Derivatives of methane, CH_4, in which three halogen atoms (chlorine or bromine) are substituted for three of the hydrogen atoms. Often formed during chlorination by reactions with natural organic materials in the water. The resulting compounds (THMs) are suspected of causing cancer.

TUBE SETTLER TUBE SETTLER

A device that uses bundles of small bore (2 to 3 inches or 50 to 75 mm) tubes installed on an incline as an aid to sedimentation. The tubes may come in a variety of shapes including circular and rectangular. As water rises within the tubes, settling solids fall to the tube surface. As the sludge (from the settled solids) in the tube gains weight, it moves down the tubes and settles to the bottom of the basin for removal by conventional sludge collection means. Tube settlers are sometimes installed in sedimentation basins and clarifiers to improve particle removal.

TUBERCLE (TOO-burr-cull) TUBERCLE

A protective crust of corrosion products (rust) which builds up over a pit caused by the loss of metal due to corrosion.

TUBERCULATION (too-BURR-que-LAY-shun) TUBERCULATION

The development or formation of small mounds of corrosion products (rust) on the inside of iron pipe. These mounds (tubercules) increase the roughness of the inside of the pipe thus increasing resistance to water flow (increases the C Factor).

TURBID TURBID

Having a cloudy or muddy appearance.

TURBIDIMETER TURBIDIMETER

See TURBIDITY METER.

TURBIDITY (ter-BID-it-tee) TURBIDITY

The cloudy appearance of water caused by the presence of suspended and colloidal matter. In the waterworks field, a turbidity measurement is used to indicate the clarity of water. Technically, turbidity is an optical property of the water based on the amount of light reflected by suspended particles. Turbidity cannot be directly equated to suspended solids because white particles reflect more light than dark-colored particles and many small particles will reflect more light than an equivalent large particle.

TURBIDITY METER TURBIDITY METER

An instrument for measuring and comparing the turbidity of liquids by passing light through them and determining how much light is reflected by the particles in the liquid.

TURBIDITY UNITS (TU) TURBIDITY UNITS (TU)

Turbidity units are a measure of the cloudiness of water. If measured by a nephelometric (deflected light) instrumental procedure, turbidity units are expressed in nephelometric turbidity units (NTU) or simply TU. Those turbidity units obtained by visual methods are expressed in Jackson Turbidity Units (JTU) which are a measure of the cloudiness of water, they are used to indicate the clarity of water. There is no real connection between NTUs and JTUs. The Jackson turbidimeter is a visual method and the nephelometer is an instrumental method based on deflected light.

TURN-DOWN RATIO TURN-DOWN RATIO

The ratio of the design range to the range of acceptable accuracy or precision of an instrument. Also see EFFECTIVE RANGE.

UNIFORMITY COEFFICIENT (U.C.) UNIFORMITY COEFFICIENT (U.C.)

The ratio of (1) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 60 percent of the material (by weight) to pass through, to (2) the diameter of a grain (particle) of a size that is barely too large to pass through a sieve that allows 10 percent of the material (by weight) to pass through.

$$\text{Uniformity Coefficient} = \frac{\text{Particle Diameter}_{60\%}}{\text{Particle Diameter}_{10\%}}$$

VARIABLE FREQUENCY DRIVE VARIABLE FREQUENCY DRIVE

A control system that allows the frequency of the current applied to a motor to be varied. The motor is connected to a low-frequency source while standing still; the frequency is then increased gradually until the motor and pump (or other driven machine) is at the desired speed.

VARIABLE, MEASURED VARIABLE, MEASURED

A factor (flow, temperature) that is sensed and quantified (reduced to a reading of some kind) by a primary element or sensor.

VARIABLE, PROCESS VARIABLE, PROCESS

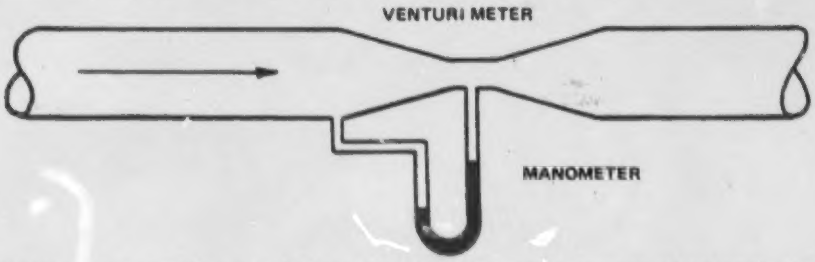
A physical or chemical quantity which is usually measured and controlled in the operation of a water treatment plant or an industrial plant.

VELOCITY HEAD VELOCITY HEAD

The energy in flowing water as determined by a vertical height (in feet or meters) equal to the square of the velocity of flowing water divided by twice the acceleration due to gravity ($V^2/2g$).

VENTURI METER VENTURI METER

A flow measuring device placed in a pipe. The device consists of a tube whose diameter gradually decreases to a throat and then gradually expands to the diameter of the pipe. The flow is determined on the basis of the differences in pressure (caused by different velocity heads) between the entrance and throat of the Venturi meter.



NOTE: Most Venturi meters have pressure sensing taps rather than a manometer to measure the pressure difference. The upstream tap is the high pressure tap or side of the monometer.

VISCOSITY (vis-KOSS-uh-tee) VISCOSITY

A property of water, or any other fluid, which resists efforts to change its shape or flow. Syrup is more viscous (has a higher viscosity) than water. The viscosity of water increases significantly as temperatures decrease. Motor oil is rated by how thick (viscous) it is; 20 weight oil is considered relatively thin while 50 weight oil is relatively thick or viscous.

VOID VOID

A pore or open space in rock, soil or other granular material, not occupied by solid matter. The pore or open space may be occupied by air, water, or other gaseous or liquid material. Also called a void space or interstice.

VOLATILE (VOL-uh-tull) VOLATILE

A substance that is capable of being evaporated or easily changed to a vapor at relatively low temperatures. For example, gasoline is a highly volatile liquid.

VOLATILE ACIDS VOLATILE ACIDS

Acids produced during digestion. Fatty acids which are soluble in water and can be steam-distilled at atmospheric pressure. Also called "organic acids." Volatile acids are commonly reported as equivalent to acetic acid.

VOLATILE LIQUIDS VOLATILE LIQUIDS

Liquids which easily vaporize or evaporate at room temperatures.

VOLATILE SOLIDS VOLATILE SOLIDS

Those solids in water or other liquids that are lost on ignition of the dry solids at 550°C.

VOLTAGE
VOLTAGE

The electrical pressure available to cause a flow of current (amperage) when an electrical circuit is closed. See ELECTROMOTIVE FORCE (E.M.F.).

VOLUMETRIC
VOLUMETRIC

A measurement based on the volume of some factor. Volumetric titration is a means of measuring unknown concentrations of water quality indicators in a sample by determining the volume of titrant or liquid reagent needed to complete particular reactions.

VORTEX
VORTEX

A revolving mass of water which forms a whirlpool. This whirlpool is caused by water flowing out of a small opening in the bottom of a basin or reservoir. A funnel-shaped opening is created downward from the water surface.

WASTEWATER
WASTEWATER

The used water and solids from a community (including used water from industrial processes) that flow to a treatment plant. Storm water, surface water, and groundwater infiltration also may be included in the wastewater that enters a wastewater treatment plant. The term "sewage" usually refers to household wastes, but this word is being replaced by the term "wastewater."

WATER HAMMER
WATER HAMMER

The sound like someone hammering on a pipe that occurs when a valve is opened or closed very rapidly. When a valve position is changed quickly, the water pressure in a pipe will increase and decrease back and forth very quickly. This rise and fall in pressures can do serious damage to the system.

WATER PURVEYOR (purr-VAY-or)
WATER PURVEYOR

An agency or person that supplies water (usually potable water).

WATER TABLE
WATER TABLE

The upper surface of the zone of saturation of groundwater in an unconfined aquifier.

WATT
WATT

A unit of power equal to one joule per second. The power of a current of one ampere flowing across a potential difference of one volt.

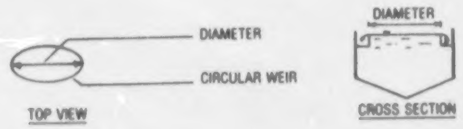
WEIR (weer)
WEIR

(1) A wall or plate placed in an open channel and used to measure the flow of water. The depth of the flow over the weir can be used to calculate the flow rate, or a chart or conversion table may be used.

(2) A wall or obstruction used to control flow (from settling tanks and clarifiers) to assure uniform flow rate and avoid short-circuiting.

WEIR DIAMETER (weer)
WEIR DIAMETER

Many circular clarifiers have a circular weir within the outside edge of the clarifier. All the water leaving the clarifier flows over this weir. The diameter of the weir is the length of a line from one edge of a weir to the opposite edge and passing through the center of the circle formed by the weir.



WEIR LOADING
WEIR LOADING

A guideline used to determine the length of weir needed on settling tanks and clarifiers in treatment plants. Used by operators to determine if weirs are hydraulically (flow) overloaded.

$$\text{Weir Loading, GPM/ft} = \frac{\text{Flow, GPM}}{\text{Length of Weir, ft}}$$

WET CHEMISTRY
WET CHEMISTRY

Laboratory procedures used to analyze a sample of water using liquid chemical solutions (wet) instead of, or in addition to, laboratory instruments.

WHOLESOME WATER
WHOLESOME WATER

A water that is safe and palatable for human consumption.

WIRE-TO-WATER EFFICIENCY
WIRE-TO-WATER EFFICIENCY

The efficiency of a pump and motor together. Also called the OVERALL EFFICIENCY.

YIELD
YIELD

The quantity of water (expressed as a rate of flow — GPM, GPH, GPD, or total quantity per year) that can be collected for a given use from surface or groundwater sources. The yield may vary with the use proposed, with the plan of development, and also with economic considerations. Also see SAFE YIELD.

ZETA POTENTIAL
ZETA POTENTIAL

In coagulation and flocculation procedures, the difference in the electrical charge between the dense layer of ions surrounding the particle and the charge of the bulk of the suspended fluid surrounding this particle. The zeta potential is usually measured in millivolts.

ZONE OF AERATION
ZONE OF AERATION

The comparatively dry soil or rock located between the ground surface and the top of the water table.

ZONE OF SATURATION
ZONE OF SATURATION

The soil or rock located below the top of the groundwater table. By definition, the zone of saturation is saturated with water. Also see WATER TABLE.

ZOOPLANKTON (ZOE-PLANK-ton)
ZOOPLANKTON

Small, usually microscopic animals (such as protozoans), found in lakes and reservoirs.

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